YOUNGSTOWN UNIVERSITY
LIBRARY

M. S. R. Morris

SMOKE

A STUDY OF TOWN AIR

SMOKE

A STUDY OF TOWN AIR

BY

JULIUS B. COHEN, PH.D., B.SC., F.R.S.

EMERITUS PROFESSOR OF ORGANIC CHEMISTRY IN THE UNIVERSITY OF LEEDS

AND

ARTHUR G. RUSTON, B.A., D.SC.

LECTURER IN AGRICULTURAL ECONOMICS IN THE DEPARTMENT OF AGRICULTURE, UNIVERSITY OF LEEDS

NEW ENLARGED EDITION

LONDON

EDWARD ARNOLD & CO.

1925

[*All rights reserved*]

YOUNGSTOWN UNIVERSITY
LIBRARY

Made and Printed in Great Britain by
Butler & Tanner Ltd., Frome and London

5.76
.C7
1925

PREFACE

First Edition

The following pages contain the records of observations which have been carried on at intervals during the last twenty years. In view of the increasing interest taken in the smoke problem in its relation to health, to the growth of vegetation, and to the disintegration of the stonework of ancient buildings, these records, some of which have already appeared in different scientific journals, are now collected together, and published in book form. We have at the same time introduced the experimental results of other observers.

Among the many aspects of the smoke problem which are included in the present inquiry, it will be seen that those only have been studied which afforded a definite and unequivocal result. We have, in consequence, felt ourselves obliged to give the health question a subordinate place. A little reflection will show that however much we may be convinced, or wish to be convinced, of the deleterious effects on health produced by breathing a smoke-laden atmosphere, ordinary medical statistics afford little definite information. It is impossible, in the majority of cases, to point with any certainty to specific cases of disease or mortality as due to this cause, or even mainly to this cause, unless it be during the occasional occurrence of dense fog. The only statistics known to us which bear definitely on the subject are those collected by Dr. Ascher, medical officer of Hamm, Westphalia, which have

119453

been contributed to this volume at our request, and for which we offer him our grateful thanks. They will be found in Appendix A, pp. 93–97.

By avoiding unnecessary scientific detail, the material is presented in a manner which, it is hoped, may be readily understood by the non-scientific reader.

Second Edition

Since the first edition of this volume appeared, there have been clear signs of a steadily growing interest in the smoke problem.

In 1912, under the auspices of the Coal Smoke Abatement Society, an International Smoke Abatement Exhibition was opened at Islington, meetings and conferences were held and a committee on atmospheric pollution was appointed. This committee, which was afterwards incorporated with the Meteorological Office, as an advisory committee, devised and carried out a scheme for obtaining records in different towns of atmospheric pollution, following one of the methods adopted and described by us, namely, an estimation of the insoluble and soluble impurities carried down by rain. These records have been continued up to the present and form the material of nine annual reports. At the same time a Smoke Abatement League of Great Britain was inaugurated and has been active in promoting conferences and exhibitions of smoke preventing appliances and in other ways furthering the cause of smoke abatement.

Two smoke abatement bills have been introduced since 1912, one by Mr. A. G. C. Harvey, M.P., in 1913, which was not proceeded with, and another by Lord Newton in 1914 which led directly to the appointment of a departmental

committee by Sir H. Samuel, President of the Local Government Board.

This committee, which began its sittings under the chairmanship of Mr. Russell Rae, M.P. (upon which one of us was elected to serve), was suspended during the war. A reconstituted committee, which was appointed in 1920 by Dr. Addison, Minister of Health, with Lord Newton as chairman, issued an interim report the same year and a final report in 1921. In these reports certain recommendations were made in view of future legislation, and a bill was drawn up for presentation to the House of Lords by the Earl of Onslow in 1922 but has not yet been proceeded with. It should be added that this bill has not been approved in its entirety by the Sanitary Inspectors' Association, an energetic and experienced body whose opinion deserves careful consideration.

Sufficient will have been said to indicate how much public feeling is being aroused by this ever present nuisance.

Some important additions have been made to the material presented in the first edition, notably to the effect of smoke on vegetation, and a section has been added on "the plant as an index of smoke pollution."

There are short references to the work of the Advisory Committee on Atmospheric Pollution, the Standard Gauge, Dr. Owens' Automatic Filter and Dust Counter and the comprehensive work on the disintegration of masonry by Sir Frank Barnes, to whose courtesy we are greatly indebted for the photographs illustrating this section.

J. B. COHEN.
A. G. RUSTON.

LEEDS,
March, 1925.

CONTENTS

	PAGE
INTRODUCTION	1
THE SOLID PRODUCTS OF COMBUSTION	4
1. Composition of Soot	4
2. The Acidity of Soot	7
3. The Amount of Soot emitted from Chimneys	7
4. The Amount of Solid Impurities in the Air	11
5. The Daily Soot-Fall	13
6. Soot-tar, its Amount and its Effects	20
7. Effects of Soot on Vegetation	23
8. Assimilation by Leaves of Evergreens	25
9. Influence of Smoke on the Intensity of Light	35
GASEOUS IMPURITIES	39
1. Sulphur Acids	39
2. Effects of Sulphuric Acid on Masonry	45
3. Effects of Sulphuric Acid on Metal Work	52
4. Effects of Sulphuric Acid on Vegetation	53
5. Other Gaseous Products of Combustion and their Effects	60
6. Arsenic in Coal, Soot, and Rain	63
TOWN FOG	66
THE DISPERSAL OF SOOT	77
THE PLANT AS AN INDEX OF SMOKE POLLUTION	78
APPENDIX A. The Influence of Coal-Smoke upon Health	93
,, B. Analyses and Manurial Value of Soot	98
,, C. Analyses of Leeds Rain-water	102
,, D. Smoke and the Electrification of Plants	105
INDEX	107

LIST OF PLATES

PLATE		FACING PAGE
	A View of Leeds, overlooking Kirkstall Road. *Frontispiece*	
I	Tower of London: Bloody Tower	14
II	Appearance of Melted Snow and Rain-water in Smoke-laden Locality	15
III	Effect of Smoke on Leaves	22
IV	Assimilation of Carbon Dioxide by Leaves	23
V	Effect of Smoke on Growth of Ash Trees	28
VI	Roots of Plants grown at different Centres	29
VII	Lettuces grown at different Centres	32
VIII	Radishes and Spring Cabbages grown at different Centres	33
IX, X	Effect of various Proportions of Sulphuric Acid in Water on Growth of Timothy Grass	52, 53
XI	Somerset House: Quadrangle Houses of Parliament: Cloisters	68
XII	Buckingham Palace Hampton Court Palace	69
XIII	Section through Stem of Scotch Fir Black Fringe of Soot on Coniston Lake	78
XIV	Barley and Oats grown in Different Localities	79

"There was a time, both in England and on the Continent, when smoke was considered a necessary evil which had to be suffered. After a while smoke began to be looked upon as a nuisance, and war was declared against it by those who suffered from its disagreeable properties; but now we know that smoke is a waste, and that nobody has better cause to wage war against it than he who produces it. . . . Smoking chimneys are thieves and their misdeeds should not rise unavenged to Heaven. . . . It is, perhaps, not too much to say that the saving of national wealth effected by regenerative gas heating may amount to a sum sufficient to pay the aggregate national debts of all the civilised nations.

O. N. WITT.

Address to the Seventh International Congress of Applied Chemistry, held in London, May 31, 1909.

SMOKE

A STUDY OF TOWN AIR

INTRODUCTION

THE subject of the emission of coal smoke from chimneys is one which has for many years past forced itself with increasing prominence upon the notice of those residing in the larger towns.

It is admittedly its æsthetic rather than its economic aspect which has appealed, in the first instance, to popular sentiment. Blackened buildings, darkened skies, and the general air of dirt and gloom which are typical of an English industrial centre have aroused a growing feeling of dissatisfaction among a certain section of the community, and have led to the formation here and there of societies for the prevention of smoke. Some of these societies have pursued their object with praiseworthy energy. By means of pamphlets, public addresses, conferences and exhibitions of smoke-preventing appliances they have sought to enlist public sympathy. They have pointed to the loss of fuel which coal smoke entails, to the physical deterioration and lowered vitality of the inhabitants of towns caused by inhaling a contaminated atmosphere, to the loss of daylight, and to the destruction of vegetation.

It is a remarkable fact, nevertheless, that in face of the active propaganda of these societies, and a very widespread sympathy with their aims, as well as the existence of certain repressive legislative measures directed against the smoke of factories, placed in the hands of the local authority, the emission of smoke continues with almost unabated vigour from both house and factory chimneys.

It might be interesting to inquire into the cause of this

general apathy, and of the practical failure of local control. It is in reality not difficult to explain.

In the first place, there is the inertia of established custom which resists any change, especially in domestic organization.

Assuming the existence of an effective system of burning fuel without smoke both for domestic and factory purposes, it would be difficult to persuade manufacturers or householders to adopt it unless it offered a substantial monetary saving more than sufficient to cover the initial outlay. In the second place, private and commercial interests dominate to a large extent our civic life. The authorities are rightly unwilling to interfere with the business of the manufacturer, or with the liberty of the private citizen, excepting in matters seriously affecting the public weal. It is useless to appeal to them on the ground that coal smoke is unsightly, or in a vague sort of way that it lowers vitality, or destroys vegetation. Æsthetic considerations possess little weight with the Legislature, and the effect of smoke on health must be very clearly proved before action is taken. Thus, no President of the Local Government Board has yet ventured to pledge himself to any definite policy for meeting the evil of smoke by more effective means than our present system affords, however inadequate that may be. Not even the enormous aggregate loss of fuel, amounting to nearly two and a half million tons, which passes into the air as smoke, disturbs him (see p. 11). That is the private concern of the householder and manufacturer. Thus matters are at a standstill. But if it can be shown beyond any question that the effects of smoke are distinctly injurious to health, or clearly pernicious in other ways, and that its removal can be effected without serious expense or discomfort, then the authorities have not only the right, but a positive duty to interfere and enforce more drastic means for its suppression. The question, then, arises : Have we any trustworthy information on the subject ? What is the nature of soot ? What is the quantity emitted from domestic and from factory chimneys, and what is the quantity temporarily and permanently deposited ? What is the quantity suspended in the air, and to what extent does it affect health ? Does it corrode as well as discolour masonry, brickwork, and metalwork, and how far is it destructive to vegetation ? Do its effects extend beyond the immediate vicinity of the town ;

to what extent does it shut out daylight, induce or aggravate fog ? and, finally, what is the increased cost of cleaning ?

It is to some of these questions that we have been trying to obtain definite answers. We have not entered at all into the subject of the cause and cure for smoke, which have been very thoroughly examined and discussed by other writers. Our attention has been directed to collecting together data on the imperfect combustion of coal, and presenting an accurate picture of the results.

It is hoped that these facts will enable smoke abatement societies and others who are interested in the suppression of smoke to appeal with additional force and greater success than has hitherto attended their efforts to the central authority as well as to the general public.

THE SOLID PRODUCTS OF COMBUSTION

1. The Composition of Soot

A VERY important—perhaps the most important—feature of the smoke problem lies in the nature of soot. Soot consists mainly of carbon, tar, and ash (mineral matter), together with small quantities of sulphur, arsenic, and nitrogen compounds, and frequently possesses an acid character. If it were entirely composed of carbon and mineral matter it would be rapidly removed by the first heavy rainfall, and there would probably be no steady accumulation of grime on brickwork, masonry, and vegetation, such as strikes the eye on entering a large manufacturing town. But the tar which soot contains causes it to adhere like a varnish, even to the polished surface of glass from which a current of water will not detach it.

The analyses of soot which have been made from time to time by different experimenters show great variations in composition.[1] When one considers the very different conditions under which coal is burnt in the factory and the home, it is obvious that the character of the soot must vary. For soot is a product of incomplete combustion, and is formed partly by the mechanical removal of dust by the chimney draught, and partly by the decomposition of the fuel such as occurs in the process of destructive distillation. It might, therefore, be expected that the higher temperature and stronger draught of a factory furnace would produce a soot more by

[1] W. C. Roberts-Austen, *Report on the London Smoke Abatement Exhibition*, p. 9; *Report of the Manchester Air Analysis Committee* (1891), p. 7; Cohen and Hefford, *J. Soc. Chem. Ind.* (1893), **12.** 4; W. Irwin, *J. Soc. Chem. Ind.* (1902), **21.** 533; E. Knecht, *Mem. Lit. and Phil. Soc. Manchester* (1905), **49.** 14; R. H. Clayton, *J. Gas Lighting* (1907), **100.** 427.

mechanical removal and less by incomplete combustion than a domestic grate, in other words, a soot containing more ash and less tar.

Not only is this the case but the character of the soot varies with the distance from the grate at which it has been deposited.

The analyses given below illustrate these facts very clearly.

The method of analysis was to extract the dried soot with ether to remove the tar (which was then estimated by distilling off the ether) and to burn the residue in a current of oxygen by the ordinary process.[1]

The first table gives the analyses of soot from domestic fireplaces. The composition of the coal used is given in the second column, the composition of the soot from the kitchen flue in the third, and that at the bottom and top of the dining-room flue in the fourth and fifth columns.

Analyses of Domestic Soot from Winston Gardens, Headingley.

Constituents.	Original Coal.	Kitchen Flue.	Dining Room Flue bottom 5 ft. from grate.	Dining Room Flue top 35 ft. from grate.
Carbon . . .	76·80	52·34	36·45	37·22
Hydrogen . .	4·90	3·68	3·51	3·51
Tar	0·88	12·46	34·87	40·38
Ash . . .	1·80	17·80	5·09	4·94

It will be seen how the higher temperature of the kitchen fire and stronger draught increase the amount of ash and decrease that of the tar when compared with the dining-room sample.

The same result is given in another experiment carried out with soot from another house burning a different quality of coal, though the difference between kitchen and study flue is not so marked.

Analyses of Domestic Soot from North Grange Mount, Headingley.

Constituents.	Original Coal.	Kitchen Flue.	Study Flue.
Carbon	76·47	45·91	47·15
Hydrogen . . .	5·22	2·18	4·85
Tar	0·92	10·20	15·68
Ash	2·10	27·34	20·22

[1] The complete analyses and detailed description of the process are given in Appendix B, p. 98.

The following analyses are of soot from coal burnt in an ordinary grate and under a boiler attached to a chimney about 110 feet high.

Analyses of Soot from the University, Leeds.

Constituents.	Original Coal.	Ordinary Grate Flue	Boiler Chimney.			
			Bottom.	13 feet from base.	70 feet from base.	Top of Chimney 110 feet.
Carbon . .	69·30	40·50	19·24	16·66	21·80	27·00
Hydrogen .	4·89	4·37	2·71	0·86	1·44	1·68
Tar . . .	1·64	25·91	0·09	0·28	0·80	1·14
Ash . . .	8·48	18·16	73·37	75·04	66·04	61·80

These analyses emphasize what was stated above as to the large increase in ash and decrease in tar in the boiler chimney. The last set of analyses are of soot taken from the bottom and top of the chimney of a brass foundry in Leeds burning liquid fuel.

Analyses of Soot from a Brass Foundry, Leeds.

Constituents.	Bottom of Chimney.	Top of Chimney.
Carbon	11·36	47·71
Hydrogen	1·03	2·35
Tar	1·02	10·62
Ash	82·16	31·42

This analysis shows a much larger quantity of tar in the soot from the top of the chimney than the previous one, and affords a good illustration of the enormous variation in the composition of soot from different fuels burnt under different conditions.

In connection with the subject of the proportion of tar in soot,[1] reference should be made to the table on p. 16, giving the analyses of the suspended matter carried down by rain-water in different parts of Leeds. It will be seen that the proportion of tar is larger in the residential than in the industrial quarters of

[1] Monthly Weather Report of the Meteorological Office for April, 1895, p. 9.

the city, and varying from about 4·5 per cent. at Hunslet, the centre of a large industrial area, to over 15 per cent. at Roundhay on the outskirts of the city.

2. The Acidity of Soot

An important feature of soot is its liability to contain acid. Dr. Russell found no acid in rain-water (p. 40) unless soot was present, and he was able to wash out the acid from soot with water and estimate its amount by titrating with decinormal alkali. The amount of free acid in 9 samples calculated as percentage of sulphuric acid was as follows :—

1·4, 0·5, 7·2, 0·0, 0·0, 4·9, 0·8, 1·2, 2·3.

Dr. Russell remarks that "if the soot in the London air be generally acid its adherence to bodies and subsequent moistening by rain will tend to corrode those bodies, and as the surface becomes roughened so will the soot more readily and more firmly adhere and the disintegrating action will proceed with increased rapidity."

Our own experiments performed in the same manner and calculated as sulphuric acid have given similar results (see also p. 42). The original coal was entirely free from acid.

Percentage of Free Acid Calculated as Sulphuric Acid in Soot.

Source of Sample.	Base of Chimney.	Top of Chimney.
Soot from brass foundry . . .	0·0	0·65
North Grange Mount study flue .	0·50	—
„ „ kitchen flue	0·0	—
The University fire-place . . .	0·37	—
„ „ boiler	1·62	0·56
Winston Gardens dining-room .	0·92	0·92
„ „ kitchen . . .	0·28	—

3. The Amount of Soot emitted from Chimneys

Of the actual amount of soot emitted from factory chimneys it is clearly impossible to obtain trustworthy data. It will vary with the quality of coal, the size and structure of the chimney and the method of firing. Estimates have been made by different observers of the amount of coal which escapes combustion ; but the experiments, though numerous, are not of a very concordant character.

119453

STATE UNIVERSITY

In 1855 Delejeune [1] determined the unconsumed carbon to be 5 per cent. of the total weight. In 1858 John Graham [2] stated, from the result of his observations, that very black smoke does not contain more than 0·1 per cent. of the carbon burnt. Scheurer-Kestner,[3] in a very careful and elaborate research on flue gases from boiler furnaces, found that the carbon lost as fuel never exceeds 1 per cent., while on the average it is 0·5–0·75 per cent. A case, however, is recorded in which a coal containing 69 per cent. of carbon lost 2·03 per cent. of the fuel as soot. In the matter of house fires we have a large mass of trustworthy data in the analyses of the late Sir W. Roberts-Austen, undertaken in connection with the London Smoke Abatement Exhibition.[4] The flue gases were aspirated through a metal tube loosely packed with asbestos, then through tubes of calcium chloride to absorb water, and finally through tubes of soda-lime to absorb carbon dioxide. The aspiration was continued for 3 hours from the first lighting of the fire and the average volume of gas drawn through the tubes was 14 litres, rather more than $\frac{1}{100000}$ of that passing through the flue. On the average of 40 experiments with different kinds of grates, but burning for the most part the same fuel (Wallsend), 0·0532 grains of soot were collected during an average consumption of 12 lbs. of coal. The weight of soot collected $\times$ the volume of gas passing up the flue $=$ 5320 grains, that is, the weight of soot from 12 lbs. of coal, or rather over 6 per cent. Although this result can only be regarded as a rough estimate, it shows a remarkable agreement with our own observations, which were carried out with the main object of estimating the soot carried up the chimney.[5] The average per cent. of soot passing up the chimney in 12 analyses, including 8 of Yorkshire coals, 2 of Durham coals, and 2 of Wigan coals, amounted to 6·5 per cent. on the carbon burnt. The quantity of soot obtained in different experiments with the same kind of coal varies, as will be seen

[1] *Bull. de la Soc. d'Encouragement* (1855), p. 473.

[2] *Mem. Lit. and Phil. Soc. Manchester* (1860).

[3] *Mémoires extraits du Bull. de la Soc. Ind. de Mulhouse*, Lacroix, Paris (1875), and "Recherches sur les produits gazeux de la combustion de la houille," *Ann. Chem. Phys.* (1870), **20.** 66.

[4] *Report on the London Smoke Abatement Exhibition of* 1884.

[5] Cohen and Hefford, "Combustion of Coal in House Fires," *J. Soc. Chem. Ind.* (1893), **12.** 121; Cohen and Russell, *ibid* (1896,) **15.** 86.

from the table, p. 10. It is no doubt influenced by the manner of firing and by the amount of draught. There was no slack in any of the samples.

The determinations were carried out as follows :—

The chimney gases were aspirated through a brass tube of about half-inch diameter. The end inserted into the chimney was closed, and a narrow slit about 3 inches long was cut longitudinally at about 1 inch from the closed end, through which the chimney gases could be drawn. To the open end of the brass tube, a glass tube containing the weighed cotton-wool plug was inserted. The cotton plug was dried in a weighing bottle in the steam oven, then kept overnight in a desiccator over sulphuric acid, and weighed against another cotton plug dried in the same manner along with the experimental one, and the process repeated until consecutive weighings were constant.

The air was aspirated by means of two gas-holders, each holding about 15 litres, and the chimney gases were drawn off at the rate of about a litre a minute, which would approach the speed of the gases passing up the flue. The object of this was to prevent a greater deposition of soot in the brass tube than would occur in its progress up the chimney. Before reaching the aspirator a portion of the chimney gases was tapped by a smaller aspirator and made to pass through a drying tube and two weighed potash apparatuses. An average sample of chimney gases was thus obtained in which the CO_2 was determined. In this way the operation was continued for about five to six hours, and during the time 200–300 litres of chimney gases were aspirated by the large aspirator, of which 5–20 litres were drawn through the small one. A good fire was maintained all the time, and the gases were aspirated from the first lighting of the fire.

Knowing the total volume of flue gases aspirated, the percentage of carbon dioxide (after deducting that in the air), and the quantity of carbon in the coal burnt, it is a simple matter to calculate from its weight in the tube the percentage of carbon deposited in the flue from the burnt coal.

A tabulated statement of the results is given on the next page.

In column 4, the carbon in the carbon dioxide of the air, calculated at 0·04 per cent. and measured at 20°, is deducted.

This quantity, 6·5 per cent., seems a very high figure, repre-

No.	Carbon Dioxide			Soot.		Per cent. of Soot on Carbon burnt.	Name of Coal.
	Chimney Gases.	Weight of CO_2.	Weight of Carbon.	Chimney Gases.	Weight of Soot.		
	Litres.			Litres.			
1	10·0	0·045	0·0102	218·0	0·0155	6·9	
2	10·5	0·0435	0·0097	282·5	0·0267	10·2	
3	9·5	0·037	0·0082	249·5	0·0174	8·0	
4	7·0	0·0485	0·0118	231·0	0·0228	5·8	"Silkstone Hards" (Yorks).
5	7·5	0·058	0·0143	164·5	0·0292	9·3	
6	7·5	0·060	0·0148	182·5	0·0219	6·0	
7	5·0	0·037	0·0091	175·0	0·0247	7·7	"Haigh Moor Best" (Yorks).
8	6·5	0·0515	0·0127	278·5	0·0278	5·1	
9	16·0	0·118	0·0289	240·0	0·0243	5·6	"Harvey Seam" (Durham).
10	6·5	0·053	0·0131	230·5	0·0227	4·8	"Hutton Seam" (Durham).
11	6·0	0·0375	0·0090	262·0	0·0282	7·1	"Best Deep Yard" (Lancs.)
12	6·0	0·0475	0·0118	230·0	0·0232	5·1	"Best Arley" (Lancs.)
Total	98·0	0·6365	0·1536	2744·0	0·2844	6·5	Mean.

senting an annual loss of more than 2 million tons on the estimated domestic consumption of 32 million tons for the United Kingdom. It is a significant fact that Sir W. Roberts-Austen found that in one case as much as 2·25 per cent. of soot on the fuel burnt was deposited in the flue itself of an ordinary fireplace, whilst in another case 0·61 per cent. collected in the flue, consisting of a sheet-iron pipe only 6 feet long. The loss estimated by R. H. Clayton [1] at 50 per cent. on the coal burnt is, of course, absurd, and is apparently a mere guess unsupported by experiments.

If, then, we take 6 per cent. as the minimum loss on the domestic coal consumption (32 million tons), and 0·5 per cent. as that on factory consumption (100 million tons), we get for the whole country a loss in the form of soot of—

	Tons.
Domestic	1,920,000
Factory	500,000
Total	2,420,000

These figures do not, of course, imply the saving which might be effected by the more efficient utilization of the calorific value of the fuel, which, according to Sir G. Beilby, amounts to something like 20 times this figure estimated as coal.[2]

The fact that gas-heating is proving more economical, convenient, and efficient for many industrial processes, and is being largely adopted by the more enterprising manufacturing firms, seems to point to a time, perhaps not far distant, when factory smoke will only form an insignificant portion of the whole amount of the products of combustion.

4. The Amount of Solid Impurities in the Air

The first accurate observations on the quantity of suspended organic matter in the air were made by the late Dr. W. J. Russell on London air.[3] He caused air, at the rate of 250 cubic feet an

[1] *J. Gas Lighting* (1907), **100.** 427.

[2] These figures are taken from the *Final Report of the Royal Commission on Coal Supplies* (1905), Vol. III. p. 11.

[3] "On the Impurities in London Air," *The Monthly Weather Report of the Meteorological Office*, August, 1885.

hour, to be pumped through a long tube plugged with clean glass wool, which was then ignited with copper oxide, and the amount of carbon and nitrogen estimated. He found for fine, dull and foggy weather (not dense fog) the following average amounts of organic matter (carbon + nitrogen) in 100 cubic feet.

	M. grams in 100 cub. ft. of air.
Fine weather	0·35
Dull „	1·03
Foggy „	2·44

Similar experiments on the amount of suspended impurities were carried out in 1897 at the Philosophical Hall, Leeds, near the centre of the town (station 4 on the map, p. 15).

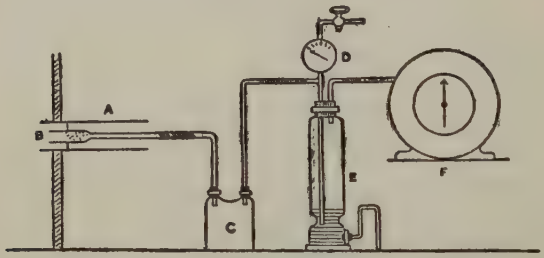


Fig. 1.—Apparatus for estimating suspended matter in air.

The air was aspirated through an aperture in a window 15 feet above the ground, overlooking a side street where there was no heavy traffic. The apparatus used for estimating the amount of suspended matter is shown in Fig. 1.

It consists of a leaden tube, A, fixed through the window, in which an open glass tube, B, is held in position by a cork diaphragm. The wide portion of the glass tube contains a weighed cotton-wool plug, and the narrow end is connected with an empty bottle, C, and a Desaga water-jet aspirator, which is attached to a large wash tower, E, so that air can be aspirated through B and C, and delivered to the experimental gas meter for measurement. The air was aspirated for about 6 hours daily during May and June, 1897, at the rate of 25 to 35 cubic feet a day.[1] The plug was weighed at intervals. Two

[1] Full details of the method given in the *J. Soc. Chem. Ind.* (1897), **16**. 411.

sets of experiments were conducted alternately, and the aggregate increase in weight is as follows :—

No. of experiment.	Cub. ft. aspirated.	Gain in weight m. grams.	Weight per 100 cub. ft. m. grams.
1	436·94	5·2	1·19
2	681·75	8·1	1·20

These figures concord very well with Dr. Russell's results for dull weather.

From this we may conclude that the weight of solid matter in the air of Leeds is 1·2 milligrams per 100 cubic feet, and as the solid matter collected on the plugs was quite black, it may be assumed that it consisted mainly of soot. Supposing this amount to be uniformly distributed through the atmosphere to a height of 300 feet before being dispersed, it will represent a weight of 2 cwt. of solid matter suspended continuously above an area of 1 square mile. If, as has been estimated, the atmosphere is renewed 50 times in 12 hours, the quantity of soot discharged into the air during this period will amount to 5 tons on the square mile. If this quantity of 5 tons is calculated for the 16 square miles covered by the city, it amounts to 80 tons. This figure is rather lower than that ascertained in other ways (see p. 23), but it must be remembered that the estimate is only a rough approximation. A portion of this soot is constantly falling, whilst the greater part is blown away.

In the report of the Advisory Committee on Atmospheric Pollution, 1916–17, p. 14, a simple contrivance devised by Dr. Owens is described by which a given volume of air is drawn through a disc of special paper of standard size and the discolouration of the paper compared with a prepared scale from which at the same time the weight of deposit can be estimated. Experiments carried out in London gave 1·5 to 3 milligrams of deposit in 100 cubic feet,[1] which, it will be observed, is rather more than that obtained by Dr. Russell and ourselves.

5. The Daily Soot-fall

Delejeune,[2] in 1855, stated that 6⅓ tons of soot fell in 12 hours in the town of Lille from a calculated loss of 5 per cent.

[1] Report of the Advisory Committee on Atmospheric Pollution, 1917–18, p. 16.

[2] *Bull. de la Soc. d'Encouragement* (1855), p. 473.

on all the fuel burnt, a number which is probably over the mark. From the quantity contained in snow which fell in the winter of 1902, Mr. W. Irwin [1] estimated roughly that 30 tons of soot fell on 100 square miles with Manchester as centre. Mr. F. W. Harris,[2] of Glasgow, from experiments with soot-collecting boxes placed in different parts of the city during the four winter months, calculated that 45 tons of soot fell each day upon Glasgow's area of 12,796 acres, or at the rate of 16,410 tons per annum, or 820 tons per square mile per annum. This is much above our estimate for Leeds, which was found to be only 220 tons per square mile per annum, or of Messrs. Des Vœux' and Owens' [3] figure for London, which was about 259 tons on the average of the four stations investigated.

A fairly accurate idea of the amount of soot falling in Leeds has been arrived at in two ways, namely, by estimating the solid impurities deposited on snow and by determining the amount of solid matter carried down by rain. In January, 1892, after a fall of snow which lay on the ground for several consecutive days during clear and frosty weather, a sample covering 1 square yard was carefully removed from a grave-stone in the parish churchyard (between stations 2 and 4, see map, p. 15) a short time after the fall had ceased. The snow was melted, filtered, and the solid estimated. Fresh samples were taken and analysed on the three following days. They contained soot in suspension, and ammonium sulphate, and chloride, calcium sulphate, and free sulphuric acid in solution. The appearance of the samples is shown in Plate II, Fig. 1, taken from a photograph. The bottle on the left representing the first day's snowfall was translucent, whilst the last of the four was quite opaque.

The weight of solid matter carried down, as determined from the first sample, was equivalent to 16 cwt. to the square mile, whilst the additional weight of soot which accumulated on each successive day was equivalent to 4 cwt. to the square mile.

By a periodical examination of the rain-water (which carries

[1] *J. Soc. Chem. Ind.* (1902), **21.** 533.

[2] "Glasgow's Smoke Nuisance," by P. Fyfe, *Glasgow Herald*, Oct. 16, 1909.

[3] "The Soot-fall of London," *The Lancet*, Jan. 6, 1912.

Tower of London: Bloody Tower.

Shows decayed Gatton stone above and new Chilmark stone below.

(*Photo taken May* 15, 1920.)

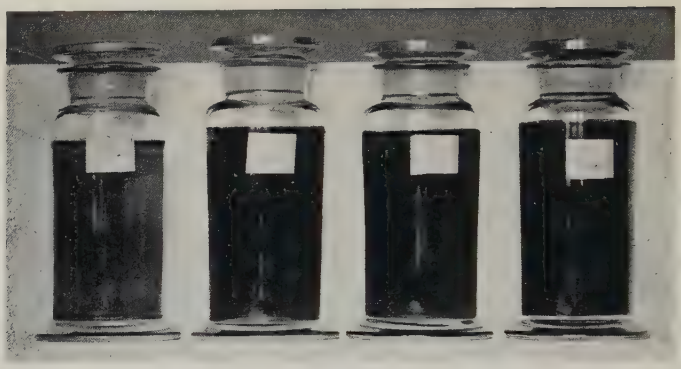


FIG. 1.—Melted snow collected on four successive days.

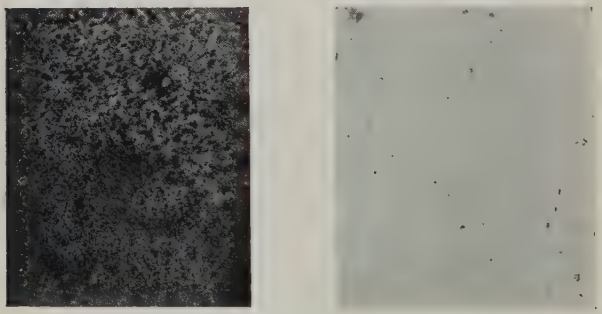


FIG. 2.—Town and country plate after 6 months' exposure.

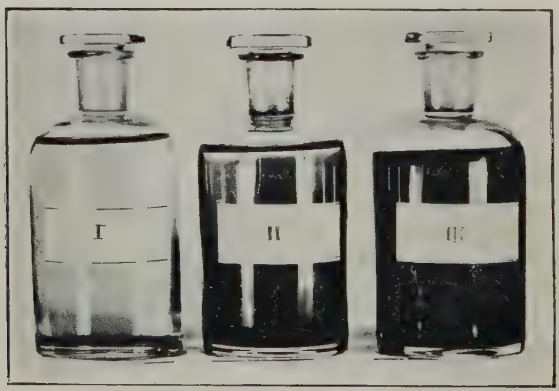
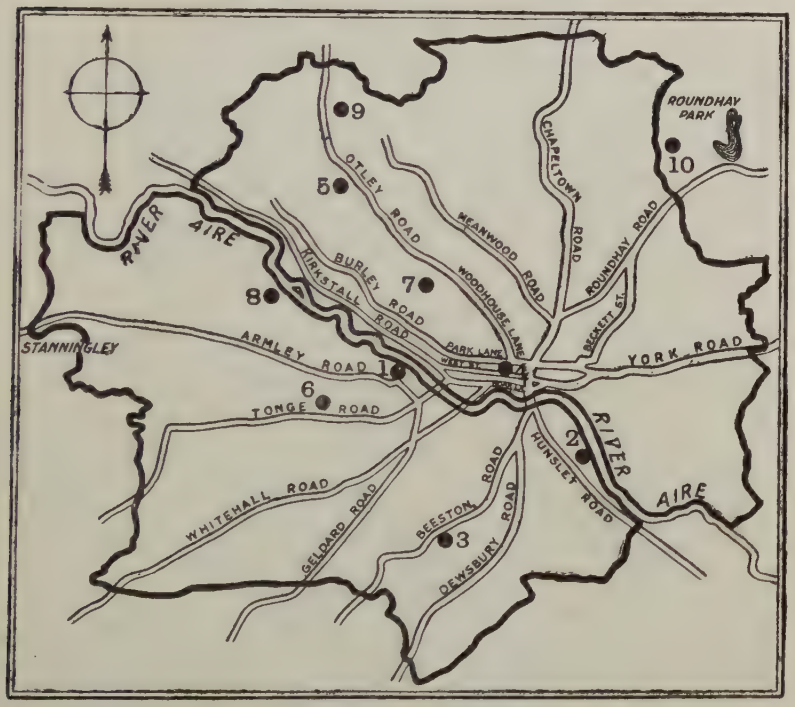


FIG. 3.—Appearance of (I) rain-water, (II) melted snow before fog, and (III) after fog.

down both soluble and insoluble impurities) derived from different localities, a fair notion of the relative quantity of these impurities has been ascertained. Ten representative stations were selected in Leeds of different types, varying from industrial to suburban, and also one at Garforth, situated about 7 miles east of Leeds in an agricultural district. The accompany-



1. Leeds Forge
2. Hunslet
3. Beeston Hill
4. Philosophical Hall

} Industrial Centres. } Town Centre.

5. Headingley
6. Armley
7. Woodhouse Moor
8. Kirkstall
9. Weetwood Lane
10. Roundhay

} Residential Centres.

FIG. 2.—Sketch-map of Leeds and its environs.

ing plan (Fig. 2) indicates the situation of the different stations (with the exception of Garforth), and the character of the area in which they were located. The rain was collected by funnels 12 inches in diameter, fitting into the necks of glass bottles, which were emptied monthly, and the contents analysed. The

results of the experiments, which were continued for 12 months from November, 1907, to October, 1908, are contained in the following table. The table gives only the suspended matter; the soluble impurities are discussed later (p. 42).

Solid Impurities in Leeds Rain.

Tons per sq. mile per annum.

		Station.	Suspended matter.			
			Carbon.	Tar.	Ash.	Total.
1	Industrial	Leeds Forge	189·6	31·4	318·0	539·0
2	Industrial	Hunslet	241·2	19·7	187·2	448·1
3	Industrial	Beeston Hill	87·1	42·6	202·5	332·2
4	Town	Philosophical Hall	99·7	22·3	120·6	242·6
5	Residential	Headingley	100·2	12·3	56·9	169·4
6	Residential	Armley	98·0	9·7	61·7	169·4
7	Residential	Woodhouse Moor	63·2	9·1	41·7	114·0
8	Residential	Kirkstall	52·3	8·0	40·3	100·6
9	Residential	Weetwood Lane	19·2	7·4	15·4	42·0
10	Residential	Roundhay	7·7	4·0	14·0	25·7
11	Residential	Garforth	—	—	—	—

The industrial area of Leeds lies almost entirely in the southern half of the city. To the north and east the city merges into purely agricultural country. These facts explain the rapid diminution in the solid impurities on passing northwards from the centre of the town. Taking the centre as the unit, 1 mile out they fall to $\frac{1}{2}$, and $2\frac{1}{2}$ miles out they fall to $\frac{1}{6}$, whilst at Roundhay, about 3 miles north-east of the centre, the impurities are $\frac{1}{20}$ of those in the industrial areas. The waste of fuel in the form of unburnt coal is illustrated here in a very striking way; for in Hunslet there is each year a deposit of nearly 450 tons per square mile, whilst the average amount for the whole area included in the investigation, roughly 16 square miles or 4 miles square, amounts to 220 tons per square mile per annum, or an average of over 15 cwt. per square mile

a day for the whole town.[1] Taking the average of 5 stations included in the 4 square mile central area we have an average of 335 tons per annum, or roughly 1 ton per square mile a day.[2]

The diagram of Fig. 3 represents by the length of the vertical columns the proportion of carbon, tar and ash in the soot from the rain of the various stations numbered on the horizontal line.

An interesting point was the effect of the coal strike of March, 1912, in diminishing this pollution and clearing the air, the change being most marked in the industrial areas, and least in the rural areas. Measuring the smoke pollution by the average amount of solid impurities in the rain (parts per 100,000) in each month, we get :—

	Feb.	March.	April.	May.	
Parts per 100,000	6·5	2·2	9·1	8·5	Industrial areas.
	2·2	1·0	4·6	4·1	Rural areas.

In each case we get a sudden drop during the month of the strike, and a marked recovery to its normal level when the strike was over (Fig. 4). This will fully explain the remarkable clearness and brightness of the atmosphere during the strike, a matter of very general observation.

A method almost identical with that just described has been recently adopted by the Advisory Committee on Atmospheric

1. Leeds Forge.
2. Hunslet.
3. Beeston Hill.
4. Philosophical Hall.
5. Headingley.
6. Armley.
7. Observatory.
8. Kirkstall.
9. Weetwood Lane.
10. Roundhay.

Fig. 3. — Relative proportion of suspended matter.

[1] Delejeune in 1855 estimated roughly that 6⅓ tons of soot fell in 12 hours in the town of Lille, a number which was probably over the mark, whereas W. Irwin (*J. Soc. Chem. Ind.* (1902), **21**. 533) estimated roughly that 30 tons fell on 100 square miles, with Manchester as centre, or 5 tons to 16 square miles.

[2] It will be noticed that the amount of deposit on the snow on successive days is about one-fifth of that carried down by rain, or one-fourth of that carried down by falling snow. It is obvious that a much smaller quantity will be deposited by gravitation in a dry atmosphere than when the atmosphere is washed by rain or snow, and that the rain will cleanse more effectively than the snow (see Appendix B, p. 98).

Pollution, under the name of the "Standard Gauge," the main difference being the use of a stoneware funnel of 12 inches diameter in place of one of glass. On the opposite page are given the numerical results calculated as tons per square mile contained in the Annual Report for 1922–23.

It is difficult to institute a comparison between the amount of atmospheric impurity in the towns enumerated in the above table, because the records extend over different periods and for different lengths of time. But there are other and more serious considerations which, in our opinion, render the

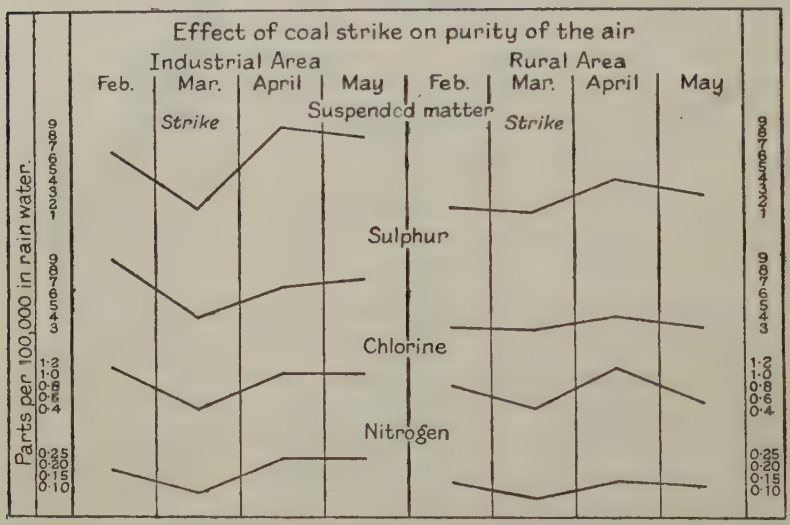


Fig. 4.

method open to criticism, a criticism which applies equally to our own observations.

Hunslet (Leeds) may very well be dirtier than any part of Glasgow or London; but it seems unlikely that Rochdale should be twice as dirty as the dirtiest part of Leeds, or that Headingley (Leeds) should be twice as clean as the purely agricultural district of Rothamsted or the cleanest part of a residential town such as Southport.

It is evident that much must depend upon the situation of the stations. In the proximity of a factory chimney or in exposed and wind-swept localities or in places where there

Average Amount of Insoluble Matter carried down by Rain (or otherwise deposited).

Tons per sq. mile per annum.[1]

Town.	Tons.	Per cent. Tar.	Period in Years.
Birmingham :			
Central	483	1·06	2
South Western	71	1·5	2
Blackburn	355	2·4	1
Glasgow :			
Alexandra Park	158	2·7	5
Bellahouston Park	110	3·0	5
Blythswood Square	210	2·3	4
Botanic Gardens	158	2·3	5
Queen's Park	120	3·0	5
Richmond Park	189	2·2	5
Ruchill Park	151	2·6	5
Tollcross Park	166	2·7	5
Victoria Park	128	3·1	5
Hull	209	1·4	5
Leeds :			
Headingley	23	2·7	10 months
Hunslet	281	2·2	1
Park Square	202	2·4	1
York Road	117	2·2	9 months
Liverpool	381	2·2	3
London :			
Meteorological Office	176	2·5	5
Archbishop's Park	217	2·1	3
Finsbury Park	209	1·6	5
Ravenscourt Park	199	2·2	5
Southwark Park	263	1·5	5
Wandsworth Common	120	2·2	4
Victoria Park	158	1·4	5
Golden Lane	212	1·1	5
Newcastle	404	—	5
Rochdale	542	—	3
Rothamsted	48	—	2
St. Helens	235	2·8	5
Southport :			
Hesketh Road	48	3·0	5
Woodvale Moss	43	—	1

[1] *Vide* Report of the Advisory Committee on Atmospheric Pollution 1922–23, Meteorological Office of the Air Ministry, pub. by H.M. Stationery Office, 1924.

is much traffic, dust, grit and soot from the immediate surroundings will be deposited along with the dirt brought down by rain and will tend to raise the average for that locality. In support of this view it may be mentioned that on one occasion a boiler chimney was observed by us to pour out grit like a young volcano, covering the immediate neighbourhood with a thick layer of this material, choking the drains and even penetrating the surrounding dwellings. It may be mentioned incidentally that the local authority refused to interfere, as grit is not specified as a nuisance in the Public Health Act, but only black smoke.

Moreover, the ratio of tar to carbonaceous matter as shown in the Report varies from month to month in a manner which seems to indicate some change in the conditions, possibly the direction of the wind, which determines the character as well as the amount of the deposit.

Thus, in the year 1916–17 the ratio of tar to carbonaceous matter in Newcastle varied in the different months from 1 : 10 to 1 : 40, indicating in the latter case a certain amount of organic matter not derived from coal.

We are inclined to think that on the whole the glass plate method or the automatic filter (see p. 23) is probably a safer guide where a comparison between one district and another, or between one town and another, has to be made. The glass plate method has this advantage over any other, in that it records the most obvious nuisance arising from smoke, namely, the permanent, grimy deposit. If we turn to the glass plate records on p. 21 and compare Headingley and Hunslet, we see at once that the permanent deposit at Headingley is a quarter and not one-twelfth that at Hunslet, as recorded by the standard gauge. If any doubt existed as to the relative distances of the two districts, the appearance of the Headingley plate would convince anyone of the filthy condition of its atmosphere, which is six times as dirty as the cleanest part of Leeds (Roundhay).

6. Soot-tar, its Amount and its Effects

Soot, as we have seen (p. 5) is not pure carbon ; but contains varying amounts of tar. This tar adheres so tenaciously

to everything that it is not even removed by rain. It is, in short, a kind of varnish. In order to ascertain the amount of this sticky material, glass plates 1 foot square were exposed horizontally at three stations, one in a garden at Pool (9 miles N.W. of Leeds), one on the roof of the University buildings (near station 7 on the map, p. 15), and one on the Philosophical Hall (station 4). These were disposed so as to be as far as possible from chimneys. The deposit on these plates after an exposure of a few weeks, loose matter having been removed by running water, was analysed and weighed. Fresh plates were then put in the place of those removed, and the process repeated from month to month. The deposit contained about 50 per cent. of carbon, and was therefore mainly soot. The proportion at the three stations was as follows : for 1 part deposited at station 4 near the centre of the town, $\frac{1}{10}$ was deposited at the University, and $\frac{1}{20}$ at Pool. The photograph (Plate II, Fig. 2) shows the difference between the town and the country plate after an exposure of 6 months.[1]

These experiments were repeated at a larger number of stations, with the following results :—

	Station.	March 23—June 23, 1910, m. grms.	June 23—Sept. 23, 1910, m. grms.	Cwts. per sq. mile per annum, total.
2.	Hunslet . . .	52·6	46·5	110
1–4.	Kirkstall Road (between 1 and 4) .	26·2	31·1	64
4.	Philosophical Hall	26·4	30·4	63
5.	Headingley . .	11·3	17·2	27
7.	Observatory (Woodhouse Moor). .	15·4	9·0	32
10.	Roundhay . . .	1·9	2·1	4·5

It will be seen that the ratio of the deposit at Roundhay to that at Hunslet is almost exactly 1 to 24, which was the ratio obtained in the previous set of experiments for town and country, and approximates to that of the total suspended matter, namely, 1 to 17 in the two localities.

Assuming that 5000 tons [2] is the daily, or 1,500,000 tons is

[1] This method may be recommended for testing the condition of the atmosphere. The plates after exposure for a certain time should be compared with plates of standard tints.

[2] This figure is taken from the ratio of coal consumption to population as ascertained for London. No other estimate seems available.

the annual coal consumption in Leeds over an area of 16 square miles, and that $\frac{1}{3}$ is burnt in house fires emitting 6 per cent. of soot, and $\frac{2}{3}$ in factories giving off 0·5 per cent. of soot, we may determine the fate of the unburnt fuel as follows [1] :—

Destination of Soot emitted in Leeds.

(Tons per annum.)

Total emitted from factories . . .	5,000
„ „ house fires . . .	30,000
	35,000
Soot blown away	31,480
„ deposited temporarily	3,472
„ „ permanently. . . .	48
	35,000

The amount which escapes is nearly 10 times that which falls, and more than 600 times that which remains as a permanent stain.

The opinion has been expressed [2] that owing to the larger percentage of tar in domestic soot and consequently its greater adhesive property, the blackening of buildings and vegetation is mainly due to the domestic fire-place. There is undoubtedly much truth in this assertion ; for if we multiply the amount of soot from residential and industrial centres by their relative content of tar we find that the industrial tar deposit is nearly equal to that of the domestic product. So that, assuming the ratio of total deposit of the industrial and residential centres to be 400 to 25, and that of the tar content in the two cases to be 2 to 30, we get $400 \times 2 = 800$ as against $25 \times 30 = 750$, which is slightly in favour of the suburban area. We must remember, however, that the industrial deposit includes soot from masses of workmen's cottages which cluster round the factories and help to raise the percentage of tar. This is shown by the amount of tar in the three industrial centres of Leeds, which varies from 4·5 to 13 per cent., and is much in excess of

[1] The permanent and temporary deposits are calculated on the average of the 5 stations in the 16-mile area covered by the town.

[2] R. H. Clayton, *J. Gas Lighting* (1907), **100.** 427.

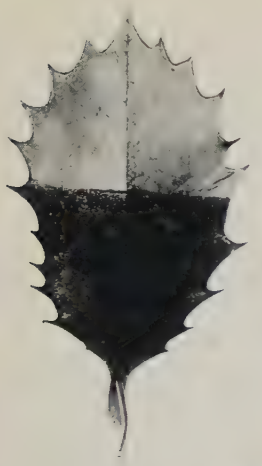


FIG. 1. — Holly leaf, half cleaned.

FIG. 3.—Leaf of ribes, showing dark rim round edge of leaf.

FIG. 2. — Laurel leaf, half cleaned.

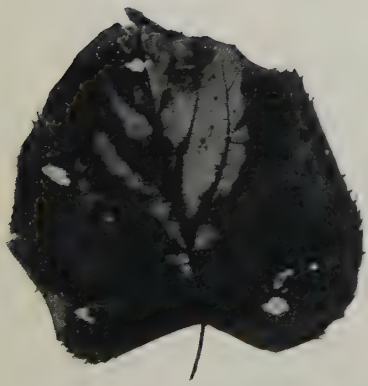


FIG. 4.—Leaf of lime, showing smoke damage.

FIG. 5.—Leaf of sycamore, showing smoke damage.

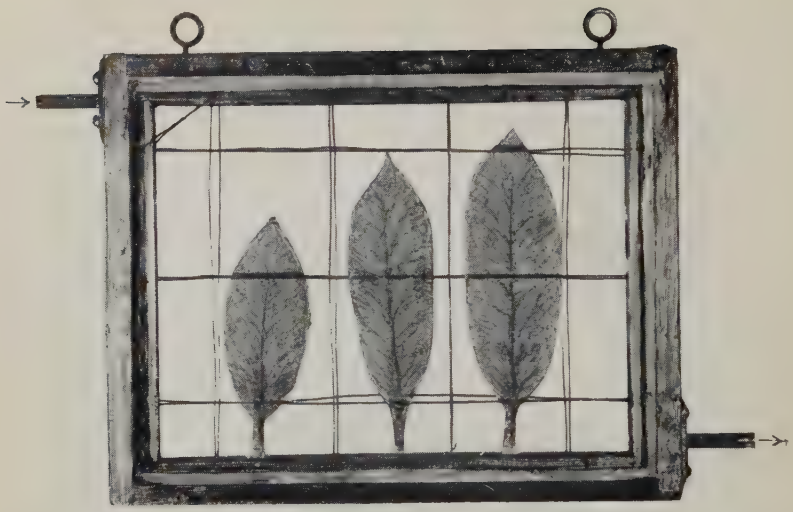


FIG. 1.—Apparatus for testing amount of carbon dioxide assimilated by leaves.

FIG. 2.—Laurel leaves and their respective assimilations.

that obtained directly from the factory chimney. Mr. Harris of Glasgow estimated, from the amount of tar found in the gases from domestic chimneys, that in the city of Glasgow 25·7 tons of tarry matter are delivered into the air every day. Our own observations on the amount of tar in soot and the quantity emitted in Leeds confirm this result. Thus, estimating as before that on 5000 tons of coal consumed daily in Leeds, $\frac{1}{3}$ is domestic and $\frac{2}{3}$ factory (taking the ratio for the whole country) and reckoning 6 per cent. loss on the domestic and 0·5 per cent. on factory consumption, there is a total loss of 117 tons daily, which, taking 20 per cent. as the content of tar, gives 23 tons of tar emitted daily. It must, of course, be remembered that Glasgow's consumption of coal is probably much higher than that of Leeds.

Another method of recording atmospheric dirt is one already referred to (p. 20) namely, filtering air through a disc of paper and comparing the discoloration produced with standard tints. This single record Owens' filter, while permitting an observation to be taken in about 10 or 15 minutes, has the disadvantage of not being automatic or continuous, nor does it take account of different coloured deposits. Mr. William Thomson [1] designed a continuous filter on the same principle and activated electrically. A more elaborate and perfect apparatus devised by Dr. Owens, namely the *automatic filter*, is described in detail in the Report of the Advisory Committee on Atmospheric Pollution, 1917–18, p. 20. This filter records automatically on a circular disc of filter paper a succession of samples of the impurity extracted from the air per hour, or at more frequent intervals, thus providing a means of examining changes in the condition of the atmosphere from hour to hour throughout the year. The changes in atmospheric impurity in the course of 24 hours in winter and summer are very interesting and are fully indicated by means of graphs in the eighth and ninth Reports of the Advisory Committee.

7. Effects of Soot on Vegetation

Soot may exert a detrimental effect on the growth of plants in three ways, namely, by blocking up the stomata and thus

[1] *J. Chem. Technology*, Vol. II, No. 4.

impeding the process of transpiration ; by coating the leaf and so reducing the intensity of sunlight, and at the same time affecting the assimilation of carbon dioxide, and lastly by the corrosive effect of the acid it contains. In both cases the tarry deposit plays an important part. The photographs shown in Plate III, Figs. 1 and 2, are taken from a holly and a laurel leaf growing in the grounds of the University. From the one half of each leaf the soot has been removed and the green colour then bleached, whilst the soot remained intact on the other half of the leaf.

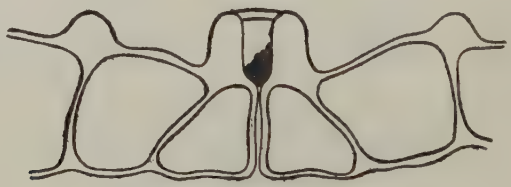


Fig. 5.—Stoma of juniper.

Fig. 6.—Stoma of silver fir.

Leaves, especially evergreens, are thus coated with a black adhesive deposit which not only absorbs the light and so arrests assimilation, but has a much more serious effect in permanently blocking up the stomata. Although the stomata are more numerous on the underside of the leaf whilst the soot tends to attach itself to the upper surface, nevertheless, an examination of the leaves of different plants has shown that those on the lower surface are also affected. The conifers appear to be the most sensitive of all plants to the influence of smoke, and their characteristic sunk stomata, which serve the purpose of minimizing transpiration, form very efficient traps for particles of soot. The only two localities in Leeds where conifers attain

even moderate growth are around the two outlying stations 9 and 10 (see p. 15). The diagrams (Figs. 5 and 6) are magnified sections through the leaf of a juniper and silver fir.

8. Assimilation by Leaves of Evergreens

The classical researches of Blackman and Horace Brown [1] have proved conclusively that the main factors influencing carbon dioxide assimilation are—

a. The number and position of the stomata.
b. The intensity of the light.
c. The temperature of the leaf.
d. The carbon dioxide content of the surrounding air.

Thus Blackman shows that it is by means of the stomatal openings that the gaseous interchanges in the leaf take place, and that if the leaf has its stomata only on the upper or lower surface, the assimilation of carbon dioxide only takes place on that side of the leaf possessing stomata. If, on the other hand, the leaf possesses stomata on both upper and lower surfaces, the carbon dioxide absorbed follows very closely the ratio of distribution of the stomata.

In the same paper he also shows that if the surface of the leaf possessing stomata be coated over with a thin layer of vaseline, thus blocking the openings, the carbon dioxide absorption is practically stopped. He has also shown that up to a temperature of about 35° there is a steady and increasing rise of assimilation, as seen from the following numbers :—

Temperature.	Grams of CO_2 per 50 sq. cm. assimilated per hour.
10°	0·0041
20°	0·0085
30°	0·0151
35°	0·0205

Brown and Escombe have found that, other factors being constant, the carbon dioxide assimilation is proportional to the percentage of carbon dioxide in the surrounding air.

In the atmosphere of industrial districts all these factors come into play. The coating of the leaves with a tarry deposit

[1] *Phil. Trans.* (1895), p. 502 ; *Proc. Roy. Soc.* (1902), p. 397 ; *Proc. Roy. Soc.* (1905), p. 402.

will act like vaseline—block up the stomata and check, if not prevent, assimilation. The smoke-cloud will lower the intensity of the light, and, by cutting off direct radiation, tend to lower the temperature, thus still further retarding assimilation. On the other hand, the slightly increased carbon dioxide content of the air of towns will tend to increase the rate of assimilation. We have no available figures of the content of carbon dioxide in the air in different parts of Leeds, but we have numerous analyses of the air of Manchester, London, Sheffield, and elsewhere, which enable us to estimate the variation in carbon dioxide.

Air in different Localities.

(Vols. of CO_2 per 10,000 vols. of Air.)

Locality.	Manchester.	London.	London.	Sheffield.	Scotch Hills.	Over Sea.
	(Angus Smith.)	(Russell.)	(Angus Smith.)	(Williams.)	(Angus Smith.)	(Thorpe.)
Town . .	4·03	4·03	4·39	3·85	—	—
Suburbs .	—	—	3·01	3·26	—	—
Country .	—	—	—	—	3·36	3·01

The difference is not great, amounting to about 1 part in 10,000, between the best and worst specimens of air. This difference will scarcely affect the plant when labouring under adverse conditions, and any advantage gained by the slightly increased carbon dioxide content is more than overbalanced by the disadvantages produced by the presence of other impurities.

A comparison [1] has been made of the rate of assimilation of carbon dioxide by laurel leaves from different parts of Leeds, the results of which are summarized in the table on p. 27. :—

The experiments were conducted as follows : Three leaves of the current season's growth were placed in a flat wooden box with glass sides (Plate IV, Fig. 1), and air drawn through each box at the rate of about 18 litres per hour for ten hours. The air, after passing over the leaves, was deprived of its carbon dioxide by means of caustic soda solution, and the amount of absorbed carbon dioxide determined by neutralization with

[1] Crowther and Ruston, *J. Agric. Science* (1911), **4**. 25.

Assimilation of CO_2 by Laurel Leaves.

Expt. No.	Source of Leaves.	Area of Leaves.	Intensity of Light.	Hourly mean temperature.	Total CO_2 assimilated.	CO_2 assimilated per 10 sq. inches per 10 hours.
	Station.	Sq. ins.	C.c. N/10 Iodine.	C.	Milligrams.	Milligrams.
1	9	36·21	1·22	10·8	21·56	5·95
2	9	23·5	3·4	17·6	40·48	17·2
3	9	23·52	1·9	13·7	36·08	11·51
	9	29·84	1·9	13·7	37·64	11·82
4	9	29·84	1·78	18·0	38·72	12·09
	5	24·35	1·78	18·0	16·72	6·86
5	9	29·84	2·12	12·6	34·32	11·50
	7	12·54	2·12	12·6	6·04	4·81
6	9	29·84	0·46	14·8	29·04	9·73
	1–7*	15·62	0·46	14·8	2·20	1·48
7	9	28·64	2·8	17·6	47·21	13·52
	4	16·42	2·8	17·6	2·64	1·56

* From a garden midway between stations 1 and 7.

standard acid, using methyl orange as indicator, after neutralization with phenolphthalein as indicator.[1] By comparison with a " blank " test the amount of carbon dioxide assimilated can be estimated. The insolation boxes were fixed outside a window with a westerly aspect, so that they received no direct radiation until late in the day, and the disturbing effect of solar heat was consequently minimized.

The intensity of daylight was measured as described on p. 35, and the area of the leaves was ascertained by means of a planimeter. In every experiment leaves from the neighbourhood of station 9 were used as the standard of comparison. Experiments 1–3 were of a preliminary nature, to test the reliability of the method. The result of Experiment 3 indicates the degree of concordance that was obtained between the rates of assimilation by different sets of leaves from the same district.

The differences in temperature and light intensity on the different days are shown by the varying rates of assimilation

[1] Brown and Escombe, *Phil. Trans.* (1900), **193.** 289; Amos, *J. Agric. Science* (1907), **1.** 322.

of the " standard " leaves, which range from 5·95 mgrms. of carbon dioxide per 10 sq. in. of leaf surface on a cold and rather dull day (Experiment 1) to 17·2 on a warm and sunny day (Experiment 2).

The laurel plants found in the more polluted areas were all very stunted in size, as compared with those growing near station 9, and consequently only medium-sized leaves could be obtained from these districts. A photograph of these leaves, which represent typical specimens from each locality, is reproduced in Plate IV, Fig. 2.

The greatly reduced assimilatory powers of these leaves, due to the direct and indirect inhibitory effects of atmospheric impurities, are well illustrated in the results of the experiments. Thus, if the assimilatory powers of leaves from station 9 equal 100, those of the leaves from the other stations are represented by the following numbers :—

Station 5	53
„ 7.	42
„ 1–7	15
„ 4.	11·5

The great reduction in the power of assimilation in passing from the non-industrial area of station 7 to the more contaminated areas of stations 4 and 5 is very striking.

In order to test the effect upon the rate of assimilation of the actual solid deposit found upon the leaves from the two last-named areas, Experiments 6 and 7 were repeated after carefully removing the soot with a dry cloth, the " standard " leaves being similarly treated. The results were as follows :—

Station	9		100
„	1–7	cleaned	24
„	1–7	not cleaned	15
„	4	cleaned	19
„	4	not cleaned	11·5

The effect is thus a measureable amount, although the power of assimilation of the cleaned leaves does not reach that of leaves grown in the atmosphere of station 9, which is freer from soot. The difference is readily accounted for by the clogging of the stomata, and the consequent lowering of the vitality of the plant.

Hunslet.
Suspended matter . 1,565 lbs. per acre
Acidity . . . . 90 ,, ,,

University.
Suspended matter . 399 lbs. per acre
Acidity . . . . 26 ,, ,,

Headingley Hill.
Suspended matter . 273 lbs. per acre
Acidity . . . . 185 ,, ,,

Weetwood Lane.
Suspended matter . 147 lbs. per acre
Acidity . . . . 11 ,, ,,

FIG. 1.—Ash trees, Sept. 18th, 1911.

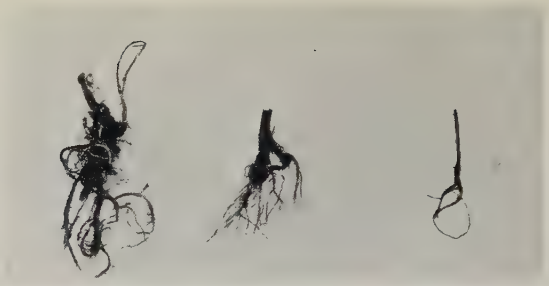
University.
Soot . 399 lbs.
Acid . 26 ,,

Headingley Hill.
Soot . 273 lbs.
Acid . 19 ,,

Weetwood Lane.
Soot . 147 lbs.
Acid . 11 ,,

Roundhay.
Suspended matter, 90 lbs. per acre. Acidity, nil.

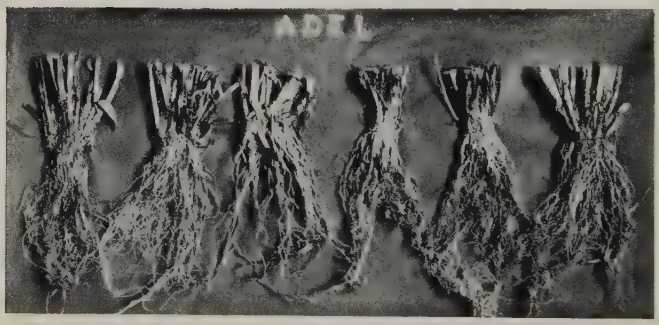
FIG. 2.—Ash trees, Oct. 30th, 1911.



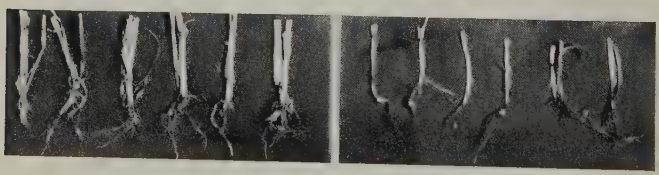
Weetwood. Garforth. Headingley.

University. Parkso. Hunslet.

FIG. 1.—Photographs of roots of wallflowers (blood red) grown at different centres.



Adel.



University. Hunslet.

FIG. 2.—Photographs of roots of oats and barley grown at different centres.

In connection with the early decay of the leaves of trees and shrubs grown in or near large towns, reference may be made to the analyses of deposits on aucuba leaves carried out by the Air Analysis Committee of the Field Naturalists' Society of Manchester. These analyses, which were made in December 1890 and January 1891, give the quantities of soot, sulphuric acid and hydrochloric acid in the deposit.[1]

Deposit on Aucuba Leaves.

In milligrams per sq. metre of leaf surface.

Date.		Locality.	Solid Deposit.	Sulphuric Acid.	Hydrochloric Acid.
1890					
Dec. 14	Suburban	Near Alexandra Park .	131	7·2	9·1
„ 13	Suburban	Owens College . . .	315	10·4	17·3
„ 16	Suburban	Hulme	420	26·0	—
„ 14	Suburban	Harpurhey	443	19·0	4·4
„ 14	Urban	Infirmary (hollies) . .	728	27·5	19·4
„ 14	Urban	„ (aucubas) .	568	18·3	14·1
„ 13	Urban	Albert Square . . .	833	24·2	21·7
1891					
Jan. 17	Sub-urban	Peel Park	374	18·0	—
„ 22	Sub-urban	Queen's Park . . .	194	17·5	—

It will be seen that the central localities show the largest deposits of soot and acid, the sulphuric acid forming 6 to 9 per cent., and the hydrochloric acid 5 to 7 per cent. of the total deposit.

The deposition of acid along with soot previously recorded by Dr. Russell (see p. 7) is probably one of the chief causes of the early withering which is characteristic of many forms of town vegetation.

Ash trees in the cleaner parts of Leeds often retain their leaves some four or even six weeks longer than those in the more polluted districts. Thus, during the autumn of 1908, near station 10, with a total suspended matter of 26 tons per square mile and acidity nil, ash trees were found in full leaf on

[1] *Report of the Air Analysis Committee of the Town Gardening Section*, 1891.

November 17th ; near station 9, with suspended matter 42 tons per square mile, and acidity equal to about 3 tons of sulphuric acid per square mile, the leaves had all fallen before the end of October, though a few were found still in leaf on the 22nd of that month ; at station 8, with suspended matter 100 tons and acidity equal to 2·28 tons per square mile, one ash tree only could be found in leaf on October 5th ; whilst at station 5, with suspended matter 189 tons and acidity 3·14 tons per square mile, all the leaves had fallen from ash trees on that date.

On September 18th, 1911, in Hunslet practically all the leaves had fallen from the ash trees which were still alive ; at the University a few leaves only were left ; at Headingley Hill the tops of the trees only had shed their leaves, while in the Weetwood Lane and Roundhay districts they appeared all to be in full vigour. By October 30th no leaves at all were left on the ash trees near the University ; a few were still left at Headingley Hill ; in the Weetwood Lane about half had fallen, while at Roundhay many of the trees appeared to have hardly shed a leaf (Plate V, Figs. 1 and 2).

Looking upon the leaf, then, as the factory of the plant, we find in the more contaminated districts this factory totally closed for one month of its working year, while, for the remainder of the time, as the assimilation experiments on p. 27 show, it is only working at half its normal pressure.

The tree automatically keeps a record of its yearly growth, and the presence of any inhibiting factor will make itself known by the narrowing of the annual rings. This is well seen in the case of the section of the Scotch fir, illustrated in Plate XIII, Fig. 1, for which we are indebted to Mr. D. W. Steuart. The tree in question was grown at Broxburn, near the Roman Camp Shale Works, which were started 17 years before it was cut down. In consequence of the acid fumes and smoke-contaminated atmosphere, the diameter growth as measured by the annual ring was sharply checked when the tree was 12 years old, though under normal circumstances it would be fairly constant up to 30 years old, and then fall steadily off. This sharply defined check in the growth of the tree, as recorded by itself, is coincident with the opening of the shale works in 1893.

Experiments have been undertaken in the Agricultural

Department of the Leeds University to find if it is possible to correlate the known atmospheric impurities in the different parts of the town with the yield of various crops.

With this object, soil was taken from the same bulk and placed in tubs which were distributed at six different stations in and near Leeds. They were sunk in the ground in open situations and sown with radishes on April 11th, 1911. In order to ensure even sowing, wire netting ($1\frac{1}{2}$ inch mesh) was placed over the tubs, and one seed dropped into each mesh (75 seeds in each tub), and three tubs were placed at each station.

They were afterwards thinned out to 30 plants, and the 90 plants from each station lifted on June 30th, weighed, dried and analysed. The conditions, except of course those determined by atmospheric impurity, were identical (Plate VIII, Fig. 1). The following are the results :—

Analyses of Radishes Grown at different Centres.

Station.	Total weight of crop. grams.	Total weight dry matter. grams.	Average weight of each plant. grams.
Weetwood Lane . . .	496	60·6	5·5
Headingley	449	51·8	5·0
Garforth	395	49·0	4·4
University	297	35·6	3·3
Park Square	242	32·2	2·7
Hunslet	226	23·1	2·5

The radishes were followed by a crop of lettuces, which were lifted on September 19th, after receiving as far as possible exactly similar treatment. Here the differences in weight were even greater than the above, only one quarter of the crop being secured in Hunslet that would have been secured had the atmospheric conditions been purer, and the smoke pollution less (Plate VII).

Yield of Lettuces Grown at different Centres.

Station.	Solid deposit. lbs. per acre.	Acidity. lbs. per acre.	Total weight of Crop. grams.	Total weight of Dry Matter. grams.
Garforth	—	—	175	18·2
Weetwood Lane . . .	147	11	140	15·1
Headingley Hill . . .	273	19	120	11·4
University.	399	26	104	10·2
Park Square	847	45	56	5·3
Hunslet	1565	90	44	4·4

The lettuces were immediately followed by winter cabbage, three plants to each box. These did not do well at any centre, but the differences between the various centres were very significant. Thus, at Station 1 (Hunslet)—the most polluted centre—every plant had died off by the middle of November. By Christmas all were dead at stations 2 and 3; five plants were alive at station 4 and seven at station 6 (Garforth). Severe frosts in February 1912 proved fatal to all the plants at Garforth and to three plants at station 4 (Headingley). Only at station 5 (Weetwood Lane) did all the plants survive the winter (save for one that had suffered mechanical damage). At the remaining stations, out of 45 plants only two survived in March, these being at station 4—the station most nearly comparable in atmospheric cleanliness with station 5.

On March 20th, 1912, the remains of the winter cabbage were removed and replaced by fresh spring cabbage plants. These were grown on until August 15th, when they were cut and weighed, etc., giving the results summarised below (see also Plate VIII, Fig. 2).

Yield of Spring Cabbage grown at different Centres.

Station.	Weight of Crop.		Per cent. of SO_3 in dry matter.
	Green.	Dry Matter.	
	Gms.	Gms.	Per cent.
1. Hunslet	505	66	4·40
2. Park Square	1,250	154	3·56
3. University	3,056	365	3·09
4. Headingley Hill	4,167	390	2·68
5. Weetwood Lane	3,425	497	2·08
6. Garforth	1,597	349	2·11

The cabbages were followed by wallflowers (Blood Red), planted out in the autumn of 1912 and left out until May 22nd, 1913. This crop, like the cabbage of the previous winter, furnished a demonstration of the inadvisability of autumn planting in smoke-infested areas. Nine plants were set out at each station; eight fairly well-grown plants were subsequently lifted alive at Weetwood (station 5), six each at

Garforth.
175 grams.

Weetwood.
140 grams.

Headingley.
120 grams.

University.
104 grams.

Park Square.
56 grams.

Hunslet.
44 grams.

Photographs of lettuces grown at different centres, with total weight of crop.

Weetwood Lane.
5·5 grams.

Headingley.
5·0 grams.

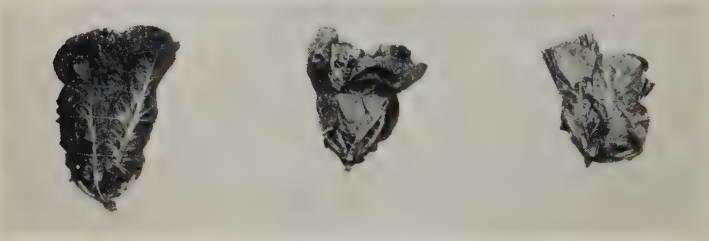
Garforth.
4·4 grams.

University.
3·3 grams.

Park Square.
2·7 grams.

Hunslet.
2·5 grams.

FIG. 1.—Photographs of radishes grown at different centres, with average weight of plant.



Headingley.
4,167 grams.

Weetwood Lane.
3,425 grams.

University.
3,056 grams.

Garforth.
1,597 grams.

Park Square.
1,250 grams.

Hunslet.
505 grams.

FIG. 2.—Photographs of spring cabbages grown at different centres, with average weight of plant.

Garforth (station 6) and Headingley (station 4), but at the other centres the plants that survived had made little or no growth, and they amounted to three only at station 3, one at station 2 and two plants at station 1.[1]

The wallflower plants from the various stations showed very characteristic differences in root-development. Those grown in the most polluted areas were marked by an almost entire absence of root hairs and fibrous roots, in many cases nothing being developed but one long tap root (Plate VI, Fig. 1). This feature we find to be still more pronounced in the case of plants grown in the native soil at each station, this having been exposed to the smoke pollution for many years.

Having completed the record of the tests made with five successive crops we may now turn to consider more closely the results obtained.

For this purpose the results for the three crops that were successively grown (1st, 2nd and 4th) are summarized on p. 34, where in order to facilitate comparison the results obtained at station 5 (Weetwood)—the cleanest of the Leeds stations—are taken as 100 in each case.

Apart from a few slight irregularities the results indicate a fairly close correlation between the relative degree of purity of the atmosphere in the neighbourhood of the stations, as assessed from our earlier observations, and the actual amount of plant growth obtainable. The correlation is further shown with the accumulation of sulphur in the plants. There is evidence, moreover, that the effects are cumulative, the Hunslet results becoming worse with each succeeding crop.

It was of interest at the close of the vegetation tests, after the soil had been exposed at each centre for three years, to compare the effects, if any, of the varying pollution of atmospheric origin, upon the properties of the soil, more especially with regard to its content of calcium carbonate and its bacteriological qualities. Accordingly samples of the soil at each station—originally, it should be remembered, all drawn

[1] These results were borne out by the further experience at station 1 during the same winter with over 200 wallflower plants and 60 violas, all well established plants, set out in the soil of the garden in which our experimental boxes were sunk. Of these plants not a single wallflower, and only two violas, survived the winter.

Analysis of Crops

Station.	Relative purity of the Air as measured by freedom from Sulphur.	Relative Weight of Crop (Station 5—100).			Relative Richness of Dry Matter in Sulphur (Station 5—100).		
		1st Crop, Radishes.	2nd Crop, Lettuce.	4th Crop, Cabbage.	Radishes.	2nd Crop, Lettuce.	4th Crop, Cabbage.
1. Hunslet . .	34	46	31	15	142	210	211
2. Park Square	37	49	40	37	156	171	171
3. University .	55	60	74	89	112	130	148
4. Headingley .	70	90	86	122	111	132	129
5. Weetwood .	100	100	100	100	100	100	100
6. Garforth . .	80	80	125	47	106	78	101

Analysis of Soil

Station.	Calcium Carbonate in Soil.	Nitrogen as Nitrates.	Total No. of Bacteria per gram of Dry Soil.	Ammonia produced from Peptone.	Ammonia converted into Nitrates.	Nitrogen fixed per gram of Mannite.
	Per cent.	Pts. per million.	Thousands.	Mgms.	Mgms.	Mgms.
1. Hunslet . .	0·12	1·2	876	64	1·2	15
2. Park Square .	0·17	0·8	798	67	1·9	18
3. University .	0·19	1·9	1,054	78	4·3	19
4. Headingley .	0·26	3·4	1,236	88	6·4	21
5. Weetwood .	0·30	4·6	1,536	105	8·7	26
6. Garforth . .	0·34	5·1	1,420	95	10·6	23

from the same bulk—were taken in the autumn of 1913 and examined. The results are summarised on p. 34.

These results indicate clearly that the detrimental effect of the smoky atmosphere upon plant-growth—especially at stations 1 and 2—is partly due to unfavourable changes in the soil—such as the steady depletion of the stock of calcium carbonate and the inhibition of the activities of the nitrogen-adapting bacteria.

9. Influence of Smoke on the Intensity of Light

The presence of suspended matter in the atmosphere has a marked effect upon the amount of sunshine. As an illustration, we may take the year 1907, when the number of hours of sunshine registered by a Jordan recorder at station 4 in the centre of Leeds was 1167, as compared with 1402 at Adel about 4 miles to the north ; in other words, the duration of sunshine in the centre of the city was diminished by 17 per cent. The records for other years tell a similar tale. But the sunshine recorder takes no account of the intensity of light below a certain limit of brightness. The amount of daylight may, however, be determined sufficiently accurately for comparative tests by the amount of iodine liberated from an acid solution of potassium iodide. A mixture of 50 c.c. of a 1 per cent. solution of potassium iodide and 10 c.c. of dilute sulphuric acid was exposed, and at the end of 24 hours the liberated iodine was estimated by titration with standard thiosulphate solution. Two sets of experiments have been made, one in 1895, chiefly during the winter months, at Kirkstall Road (between stations 1 and 4), at station 4 and at station 7, and another set in 1910, which were carried out during the month of June. The two sets of experiments are recorded in the following tables, the numbers giving the amount of the thiosulphate solution required to remove the free iodine.

It will be seen from the first table that in the centre of the industrial area the smoke cloud occasionally absorbs as much as 25 per cent. of the total daylight as compared with the suburban parts of the town, whilst from the second table which includes Garforth, seven miles from the town, it appears that fully 40 per cent. of the light was shut out from the industrial area represented by station 2.

Light Tests.

SET I.

Being a comparison of the total daylight in different parts of Leeds.

Date—1895.	Station 7. Woodhouse Moor.	Station 4. Philosophical Hall.	Station 1–4. Kirkstall Road.
July 1–7 . .	—	78·30	—
8–14 . .	—	88·30	83·60
15–21 . .	—	61·70	60·60
22–28 . .	—	65·30	58·50
Nov. 10–16 . .	22·94	—	20·61
17–23 . .	15·92	—	12·25
24–30 . .	10·20	—	6·10
Dec. 1–7 . .	10·90	—	10·34
8–14 . .	18·30	—	7·17
15–21 . .	4·50	4·80*	3·53
29– 4 . .	2·60	1·99	1·53
Jan. 5–11 . .	4·65	2·32	2·51
12–18 . .	7·88	5·60	5·51
19–25 . .	8·17	5·90	5·47
26– 1 . .	13·66	9·02	8·04
Feb. 2– 8 . .	6·56	7·20*	7·58*
9–15 . .	8·28	9·05*	10·57*
16–22 . .	3·82	4·40*	3·26

To economize space the results for each week are added together.

* The six numbers marked with an asterisk are exceptions to the general rule. For some unexplained reason, the amount of light registered on these dates is greater near the centre of the town than on the open moor.

The results exhibit a striking relation between the amount of suspended matter in the air and the intensity of the light.

These relations are indicated by the dark and light columns in the diagram of Fig. 7, the dark column giving the relative proportion of suspended matter carried down by rain (p. 17), and the light column the relative total daylight. The amount of daylight is thus seen to vary inversely with the amount of soot in the atmosphere.

The Cost of Washing.

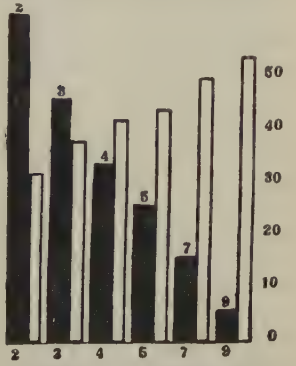
We must add to the loss occasioned by smoke a heavy domestic washing bill. In a lecture delivered to the Leeds

Light Tests.

SET II.

Date— 1910.	Station 2. Hunslet.	Station 3. Beeston Hill.	Station 4. Philo-sophical Hall.	Station 5. Head-ingley.	Station 7. Observa-tory.	Station 9. Weet-wood Lane.	Station 11. Garforth.
May 29	5·5	5·4	—	6·2	—	6·8	7·2
„ 30	4·6	4·6	—	5·1	—	5·8	6·3
„ 31	3·2	3·6	—	4·4	—	5·2	5·6
June 1	3·5	3·8	—	4·9	—	4·6	5·3
„ 2	4·7	4·8	—	4·9	—	5·6	5·7
„ 3	5·4	5·4	5·4	5·7	5·5	5·9	5·6
„ 4	2·9	2·9	3·2	3·4	3·6	3·8	4·2
„ 5	3·0	3·5	3·8	4·3	5·1	5·4	4·5
„ 6	2·9	3·1	4·6	4·8	5·0	5·6	6·3
„ 7	4·5	4·8	5·6	5·7	5·9	6·1	6·7
„ 8	2·1	3·9	4·5	4·8	5·0	5·2	5·8
„ 9	2·2	4·2	4·2	4·4	4·6	4·5	4·9
„ 10	2·0	2·4	4·2	4·4	4·7	5·0	4·8
„ 11	2·0	3·6	3·6	3·9	4·7	5·2	5·0
„ 12	3·3	5·2	5·9	6·0	6·3	6·4	6·8
„ 13	2·0	4·6	4·9	5·0	5·1	5·2	5·6
„ 14	3·1	4·0	4·9	5·1	5·3	5·2	5·0
„ 15	2·1	3·2	4·1	3·9	4·6	4·8	5·1
„ 16	2·1	3·5	4·1	4·0	4·5	4·9	4·7

Philosophical Society in 1896 I mentioned a fact which illustrates this point. A lady who formerly resided in Leeds and removed to a similar establishment in the country (*i.e.*, the same size of house and the same servants) informed me (being a careful and strict housekeeper) that the quantity of soap used in cleaning a room is less than half of that used in Leeds, the labour of cleaning less than a quarter. Windows which required cleaning once a week in Leeds, only required it once a fortnight and sometimes once a month in her present house. White curtains



2. Hunslet. 3. Beeston Hill. 4. Philosophical Hall. 5. Headingley. 7. Observatory. 9. Weetwood Lane.

FIG. 7.—Influence of suspended matter on intensity of light.

which were black in three weeks in Leeds, now lasted eighteen months. Generally speaking white fabrics lasted three times as long as formerly; the gilding of pictures and the silver and brass work remained free from discoloration for long periods. If three servants were required to do the work of a town house, two would do it easily in the country.

It has been estimated as the result of a very careful inquiry [1] that the cost of household washing in Manchester would be reduced by about £250,000 a year if Manchester were as clean as Harrogate.

[1] *The Smokeless City*, by E. D. Simon, M.I.C.E., M.I.M.E., and Marion Fitzgerald, A.R.San.Inst.

GASEOUS IMPURITIES

1. Sulphur Acids

Coal contains small quantities of sulphur, the amount of which varies between 1 and 2 per cent. On complete combustion the sulphur is evolved as sulphur dioxide, which in contact with air and moisture passes rapidly into sulphuric acid. This acid is a strongly corrosive substance. It attacks mortar, masonry, fabrics, and metal-work, and is highly injurious to vegetation, as we shall presently see. Coal is practically the sole source of this acid in town air ; for in pure country air it is virtually absent. Dr. Rideal [1] has calculated that if all the sulphur from 16 million tons of coal consumed annually in London passed into the air as sulphuric acid, it would represent from one-half to one million tons of acid.

In incomplete combustion, such as occurs more particularly in the domestic grate, a portion of the sulphur is retained in the cinder, and some in the soot. Cohen and Hefford[2] found that the distribution of the sulphur in the products of combustion of two kinds of coal, burnt in an ordinary grate in percentages of total sulphur, was as follows :—

Distribution of Sulphur Compounds from Burning Coal.

	A	B
Passing out as sulphur gases . .	71·78	60·00
Absorbed in the soot and mainly escaping	14·51	11·88
Left behind in the cinder . . .	13·71	28·13

Of that which is retained in the soot, a part is in the form of free acid, as seen from the following analyses :—

[1] *Coal Smoke Abatement Conference*, 1905.
[2] *J. Soc. Chem. Ind.* (1893), **12.** 121.

Source of Soot.	Sulphur.	Acidity.
Leeds University, fire-grate chimney	2·99	0·37
„ „ boiler chimney	2·67	1·33
Winston Gardens, dining-room	2·45	0·92
„ „ kitchen	2·20	0·28
North Grange Mount, study	2·32	0·50
„ „ „ kitchen	1·46	0·50

Rideal [1] found in samples of soot from London, Manchester, and Glasgow, an amount of acid corresponding to 4·6, 4·3, and 7·9 per cent. of SO_3 respectively. The soot which fell on the glass roofs in the gardens of Kew and Chelsea contained nearly 5 per cent. of SO_3.

The deposition of acid along with soot upon the leaves of plants is a matter of no small importance, for it is probably one of the chief causes of the early withering of leaves which is so characteristic of trees growing in and near towns.

The amount of sulphur compounds, present as free sulphurous or sulphuric acid, or in combination as sulphate in London air, has been very exhaustively studied by Dr. W. J. Russell.[2]

Dr. Angus Smith, in his work on *Air and Rain*, gives a few analyses of samples of rain, and suggests that much might be learnt of the composition of the air by examining the impurities carried down by rain-water.

Dr. Russell employed this method, and later devised a process for washing large quantities of air. He found the principal impurities in the rain of towns to be sulphates and chlorides, and expressed these as sulphuric acid and hydrochloric acid per litre of rain-water. The amount of free acid was not estimated, as the majority of the samples, unlike Leeds rain, gave no acid reaction. Three stations were selected, one in the city at St. Bartholomew's, and two suburban stations at Hamilton Terrace and Shacklewell. The amounts obtained in parts per million were as follows:—

	H_2SO_4 in parts per million.	HCl in parts per million.
St. Bartholomew's	38·8	17·9
Hamilton Terrace	19·6	8·8
Shacklewell	20·7	7·8

[1] For complete analyses, see Appendix B, p. 98.

[2] *The Monthly Weather Report of the Meteorological Office*, Parts I, II, and III, April, 1884, and August, 1885.

Thus, the city rain contained twice as much impurity as that collected at the suburban stations. Dr. Russell also found that at all three stations there was a notable increase in the proportion of sulphate during the summer months, which he put down partly to evaporation of the samples, and partly to volatile sulphur compounds being emitted from decomposing animal and vegetable matter.

Some experiments made by condensing and collecting the moisture in the air at St. Bartholomew's showed the same ratio of sulphate to chloride as well as the same amount per million parts as that in rain-water of the same locality.

An interesting illustration is also given of the purifying effect of rain on the atmosphere in the analysis of samples at the beginning (I) and end (II) of a downpour.

	St. Bartholomew's.		Hamilton Terrace.		Shacklewell Green.	
	I.	II.	I.	II.	I.	II.
Sulphates . .	39·7	33·1	33·1	11·0	39·7	13·2
Chlorides . .	8·7	3·6	3·6	1·4	5·8	2·8

The best series of analyses of country rain are those of Messrs. Lawes, Gilbert, and Warrington of rain collected during thirteen months at Rothamsted, the means of which are as follows :—

	Parts per million.
Sulphates	4·0
Chlorates	3·3

The proximity of the sea in increasing the amount of chloride is seen in the analysis of rain collected on Dartmoor during a south-westerly storm.

	Parts per million.
Sulphates	0·5
Chlorides	8·7

We will now compare our own results of the analyses of sulphur and chlorine compounds contained in the monthly samples of rain collected at the ten Leeds stations and Garforth, giving the maximum and minimum for the year.

Variation in quantity of Sulphur and Chlorine Compounds in Leeds Rain.

(Parts per Million.)

Station	Sulphur.						Free acid expressed as H_2SO_4.		Chlorine.	
	As sulphate		In other forms		Total.					
	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
	SO_3		SO_3		SO_3					
1	29·3	11·2	10·4	0·0	39·7	11·2	9·8	0	29·2	10·8
2	34·1	15·1	8·9	1·4	42·1	17·2	14·7	0	33·2	9·1
3	87·2	17·4	25·3	3·7	85·1	21·1	11·7	0	15·8	9·0
4	65·5	16·3	17·7	2·1	83·2	26·4	18·8	0	43·2	4·7
5	33·2	17·2	11·1	3·7	42·2	24·3	3·3	1·1	24·9	5·9
6	31·8	13·3	10·9	1·1	36·7	17·8	12·7	0	14·1	8·3
7	25·9	9·4	32·6	0·9	58·5	10·3	10·8	0	33·2	2·5
8	25·7	8·9	9·0	2·6	33·5	11·4	4·6	0	8·3	4·3
9	30·8	9·3	8·3	0·0	38·0	10·4	7·5	0	19·8	1·3
10	18·3	5·0	4·9	0·0	23·2	6·2	0	0	9·3	2·3
11	16·5	7·3	9·7	1·0	26·2	8·3				

In the specimens of snow gathered on four consecutive days, and referred to on p. 14, the following quantity of sulphates was found :—

Sulphates in Snow calculated as SO_3 in parts per Million.

First day	6·3	
		3·0
Second	9·3	
		3·8
Third	13·1	
		6·6
Fourth	19·7	

These results cannot, of course, be compared with sulphates carried down by rain, but are interesting as showing a steady accumulation of this impurity even in clear weather on the surface of the ground.

Taking the amount of sulphur compounds in the whole of the rain during the year, and estimating it as tons to the square mile, we arrive at the following results :—

Sulphur in Leeds Rain.

Tons per square mile per annum.

Station No.	Free acid expressed as sulphuric acid.	Sulphur compounds expressed as SO_3.		
		As sulphate.	In other forms.	Totals.
1	10·0	35·2	12·3	47·5
2	26·7	52·9	8·6	61·5
3	8·5	77·0	19·1	96·1
4	12·9	42·5	13·7	56·2
5	3·1	32·3	11·4	43·7
6	8·3	31·4	13·1	44·5
7	7·5	24·3	14·0	38·3
8	2·3	22·0	20·0	42·0
9	3·1	23·4	4·5	27·9
10	0·0	15·1	5·7	20·8
11	8·0	18·6	7·4	26·0

The above results are reproduced in the following diagrammatic form, in which the vertical columns in Fig. 8 give the amount of total sulphur, the unshaded part representing the proportion present as sulphurous acid, and the shaded part the amount of sulphuric acid either free or combined. The second diagram (Fig. 9) gives the amount of free acid.

It is thus shown that the total sulphur in the form of sulphurous or sulphuric acid is everywhere high, but particularly so in and near the chief manufacturing areas. Fortunately a large proportion of these acids is neutralized either by the alkaline fumes thrown out by the blast furnaces, or by ammonia emitted at the same time from the burning coal (p. 62). Nevertheless free acid is present in large proportion, and represents in Hunslet an annual deposit of nearly 27 tons to the square mile.

Although it is the sulphurous acid which imparts to town fog its acrid and irritating effects (see p. 68), it is the sulphuric acid which is mainly responsible for the serious damage produced on masonry and vegetation.

Before concluding this section on the subject of sulphur compounds in air, reference should be made to Dr. Russell's

experiments on washing air (*loc. cit.*). The air was pumped into a wide vertical glass cylinder 2 feet 9 inches long and $2\frac{3}{4}$ inches in diameter, which was divided vertically and horizontally into compartments by means of wire gauze. The lower end of the washing cylinder was open and placed a little above the bottom of a glass vessel holding 400 c.c. of water. On working the pump the air forces the water into the cylinder and breaks it into a spray. A second washing vessel is attached to collect

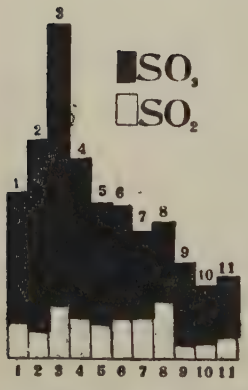


Fig. 8.—Relative amount of total sulphur.

Fig. 9.—Relative amount of acidity.

1. Leeds Forge. 2. Hunslet. 3. Beeston Hill. 4. Philosophical Hall. 5. Headingley. 6. Armley. 7. Observatory. 8. Kirkstall. 9. Weetwood Lane. 10. Roundhay. 11. Garforth.

anything which might have escaped from the first. The apparatus is shown in Fig. 10.

The mean of 27 experiments, which are divided into three groups of fine, dull, and foggy weather, are expressed in mgrms. per 100 cubic feet as follows :—

	Sulphates as Sulphuric acid.	Chlorides as Hydrochloric acid.
Fine weather . . .	1·28	0·10
Dull „	3·19	0·36
Foggy „	4·6	0·28

2. Effects of Sulphuric Acid on Masonry

Among the earlier records of the action of the acid in the atmosphere on buildings are those of Dr. Angus Smith, who

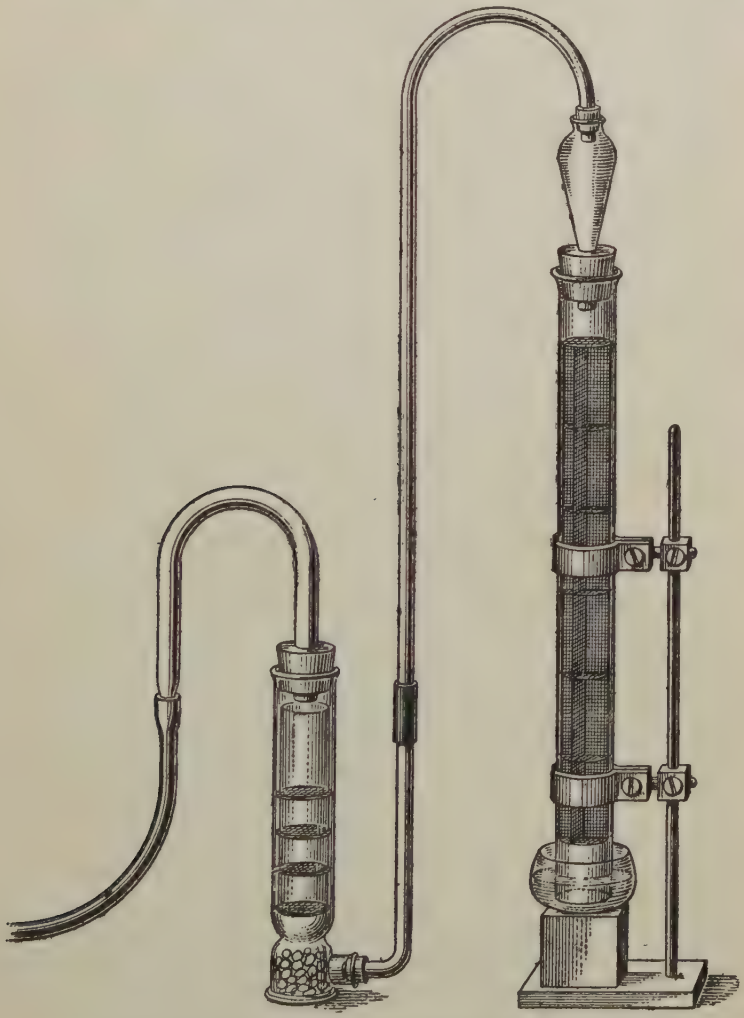


Fig. 10.—Dr. Russell's apparatus for washing air.

found in mortar 28·33 per cent. of sulphuric acid, equal to 48·16 of calcium sulphate, produced by the action of the acid on the

lime. The white efflorescence which sometimes appears on brickwork is mainly composed of calcium or magnesium sulphate, and, according to the same authority, one of the chief causes of damage done by soot and smoke is the decay of mortar. It swells, becomes porous, and falls to pieces at the slightest touch.

We are indebted to Sir H. Jackson for some of the results of his very careful and comprehensive inquiry into the effects of atmospheric sulphuric acid on the corrosion of masonry. On the stones from one historic building he reports: "All consisted mainly of calcium carbonate, being almost entirely soluble in hydrochloric acid. They showed evidence of weathering and disintegration. The surfaces of most were soft and friable, and one was so very loose and rotten that it could be removed to a depth of $\frac{1}{4}$ inch by mere rubbing. Two only had to be chipped in order to obtain portions for analysis. Chemical examination of the friable portions and of the unaffected inside of each of the stones showed that the disintegration could be ascribed to the action of sulphuric acid, which had converted part of the calcium carbonate into calcium sulphate. This was associated with an alteration in the structure of the surfaces, resulting in a loosening of the particles which had previously been cemented by the silicates which exist in small amounts as constituents of all the stones. The amount of calcium sulphate taken $\frac{1}{8}$ inch from the surface varied from 3·2 to 33·5 per cent. In one case calcium sulphate was found at a depth of nearly $\frac{1}{2}$ inch, but there was no change below that. The friability was not always proportional to the amount of calcium sulphate. Disintegration depends on the original character of the stone. Also the amount of calcium sulphate, which is soluble in water, may not represent the full extent of the conversion owing to its removal by rain." In another case he reports—

"The stone consists of calcium carbonate in granules, bound together by small quantities of calcium and aluminium silicate. A quantitative examination of scrapings taken from the inside of large pieces of stone showed that the disintegration of the stone could certainly be ascribed to the action of sulphuric acid. This acid, acting readily on the calcium carbonate, converts it into calcium sulphate and carbon dioxide. Analyses of

the calcium sulphate in the stone gave 4·75 to 15·81 per cent. on the outside, and 0·23 to 2·8 on the inside. It will be seen that fairly extensive chemical action has taken place on the outside of the stonework, but that this action has not penetrated very deeply. Limestones vary in the readiness with which they are disintegrated by the action of sulphuric acid, accompanied by the mechanical effects of wind and rain, and the present stone is somewhat easily affected by sulphuric acid. The decay has resulted from the disintegration of the surface of the stonework, accompanying the conversion of calcium carbonate into calcium sulphate by the action of sulphuric acid present in the atmosphere. This conversion has been associated with a change in the structure of the stone, so that its granules and crystals, previously held together by the cementing influence of silicates, has been attacked and partially dissolved in such a way as to loosen the hold of the cementing material upon them, and render them easily displaced by the effects of wind, rain, frost, alterations of temperature, and the mechanical disturbance arising from the crystallization of calcium sulphate."

In his report on a Kentish ragstone from a church, Sir H. Jackson says :—

" Limestones used for building purposes vary considerably in the amount of acid which can be absorbed by them before they exhibit marked deterioration. Direct experiments on portions of the ragstone show that they are affected prejudicially by relatively very small quantities of sulphuric acid. Analyses of average samples of the friable portions of the outside surfaces of the specimens gave the following percentages of calcium sulphates from 0·52 to 3·85.

" These quantities of calcium sulphate are but small compared with those frequently found in stones which have been exposed for many years to the air of towns, and which show less marked deterioration than that exhibited by the ragstone.

" The evidence of analyses from stones from various points of the building is that the decay of the stone has been primarily caused by the action of sulphuric acid present in the air, but it must be remembered that a stone weakened in its resisting power by such an action becomes much more readily affected

by water and carbonic acid, as well as by the mechanical action of frost, winds, etc."

In the course of a report on sandstone from another church, he says :—

"None of the differences in composition (between the decayed and undecayed portions) can be considered as indicating extensive chemical changes, but it must be remembered that in a sandstone consisting mainly of grains of quartz bound together by small amounts of cementing materials, a relatively slight alteration in composition may mean considerable modification in the cohesive strength of the stone. The changes indicated by analysis are such as would result in a stone of the nature of the specimens from the ordinary process of weathering, assisted by the chemical action of sulphuric acid in the atmosphere. That this acid has played some part in the disintegration appears probable when account is taken of the increase in the amount of it on the surface of the specimens, compared with that present in the body of the stone."

Two further abstracts from Sir H. Jackson's report on the stonework of another public building must suffice :—

"The results of the examination and analysis point to the disintegration of the stone having been effected mainly through the agency of the acid vapours contained in the air. Of these the most detrimental have been the sulphurous and sulphuric acid, which arise mainly from the combustion of coal. These, including carbonic acid, water, and alternations of temperature, may be described as the materials and conditions primarily necessary for the decomposition of siliceous stones (sandstones) and limestones. There is practically no evidence of any effects which can be ascribed to hydrochloric acid. In the case of siliceous stones, which consist of silica in the form of grains of quartz cemented together by aluminium silicate and calcium carbonate, the latter has been freely attacked, and its place largely taken by calcium sulphate. This, besides being soluble to an appreciable extent in water, does not act as an agglutinant for the quartz grains, which, consequently, have been rapidly displaced from their former positions.

"Disintegration having once started, would be progressive, not only on account of the continued existence of the primary causes and conditions, but because of the consequent increased

porosity of the surface of the stone rendering this a readier absorbent, both of injurious gases and of aqueous solutions, capable of chemically acting upon the materials with which they are thus brought into intimate contact."

The analyses show that in the case of limestones in many instances more than half the carbonate has been transformed into sulphate on the surface, and in the case of siliceous stones an even larger percentage of the binding carbonate has been transformed.

" It must be borne in mind, in comparing numbers for the percentages of calcium sulphate, that limestones are much more chemically active towards sulphurous and sulphuric acid than siliceous stones, and that, consequently, given the two varieties bathed in the same atmosphere, the limestones would show the higher percentage of calcium sulphate. It does not necessarily follow that they would show the greater disintegration, for with the removal of their cementing and agglutinating portions, the siliceous stones would be readily affected mechanically, as for example, by dust-laden winds and the freezing of water."

A very deeply interesting and comprehensive review of the whole subject of damage by smoke and the gaseous acid products of coal combustion to public buildings was given in an address by Sir Frank Baines, Director of H.M. Office of Works, at the recent Smoke Abatement Conference held in Manchester in November 1924 under the auspices of the Smoke Abatement League of Great Britain.[1]

His observations confirm those of Sir H. Jackson, namely, that the action of sulphur acids upon all stones having lime or magnesia in their composition is very rapid and progressive.

He said : " When sulphuric acid is brought into contact with the stone either by moisture or in tarry sooty deposits afterwards saturated with moisture, chemical reaction is set up in which part of the calcium or magnesium carbonate changes to sulphate, with the dispersal of carbon dioxide.

" The upper and more exposed parts of the stone suffer first and the flatter and projecting surfaces more than the vertical.

" The calcium sulphate is much more soluble than the

[1] The Report of the Conference may be obtained from Mr. C. Elliott, B.Sc., A.M.I.C.E., 33 Blackfriars Street, Manchester, price, post free, 5*s.* 6*d.*

carbonate, the sulphite even more so, and the streaky effect often to be noted results from water charged with these salts running down and depositing them on otherwise unaffected surfaces. Where it is checked in its flow at the soffits of cornices or strings or other projecting features or at recessed parts of carvings, sheltered corners, and indeed anywhere where the water tends to hang or creep without immediately running off, the dissolved sulphate will generally be precipitated and, with the tarry soot which also tends to collect and stick in the same sheltered position, is gradually formed the tenacious ugly black incrustations which are so common an obliteration on limestone buildings in London. A large number of pieces of these incrustations have been chemically examined, detached from Portland, Bath, Auston, Mansfield and York stones and from brickwork used in association with Portland stone, with some from slates, granite, iron, lead and zinc work. In every case sulphate was found as one of the constituents, while only in one or two cases was it found in sound parts of the material, or could it have been derived from any other source than the atmosphere. In addition to direct destruction of the stone surface by the formation of sulphate, is to be noted the great alteration of volume due to conversion of carbonates to crystalline sulphates. Where limestone is attacked and part of the calcium carbonate is replaced by sulphate, the increase in volume is from 1 to 1·7. Where magnesium carbonate is replaced by sulphate the increase is 1 to 4·2.

"When, therefore, acid-bearing water soaks into the stone and calcium and magnesium sulphate is formed, the physical condition developed may be grave enough to, and indeed does, cause exfoliation of the surface. Instances of this kind are very common, in which the presence of crystals of sulphate behind the extended flake or fragment, shows a mechanical bursting away of the face, similar to, say, frost action. The presence of flaws and cracks behind the face, face bedding of the stones, or soft pockets or layers in its structure, naturally gives greater opportunity for destruction, and quite considerable flakes or fragments are often forced off the solid stone. Parapets and balustrades often exhibit the various phenomena of this decay in proximity: pieces burst away as if sliced off as by a knife. . . .

"In softer, non-crystalline limestone, like Caen stone, exfoliation is serious and frequent, particularly where the surface has been hardened by some waterproofing preparation. Sooner or later the hard skin begins to exfoliate and the powdering of the stone behind it, already well advanced, increases by compound measure. . . . Another serious effect of atmospheric impurity is the decay in magnesian limestone (of which the Houses of Parliament are constructed).

"The formation of the sulphate is attended by a very large expansion, its ultimate bulk being about four times that of the original stone which it displaces, and as a result the building is becoming a mutilated and disfigured structure. The decay is universal over the whole area of the Houses of Parliament, and roughly 30 tons of loose pieces of stone have been taken off by hand from various parts of the structure.

"There is no need for one to dwell at length upon the decay of sandstones; they are not so directly attacked by the acids of the atmosphere as are the limestones, except when they contain calcite as the cementing material; when this is the case the calcite is destroyed by the attack of the sulphur acids and sulphate of lime is formed, the silica grains of the sand becoming loose and disintegrated and the stone breaking down.

"Mouldings, as a consequence, are eroded away, and very often large masses become detached through the percolation of the acid-laden moisture into the minute fissures or planes of cleavage.

"Of the actual effects of atmospheric acids upon stone, carbonic acid is by far the most universal and continuous in its action, but although the quantity diffused in the air is enormously greater than that of the sulphur acids, its effect is relatively mild and slow and the results of it more even and less destructive. Even the increment in quantity in town air is negligible compared with the sulphur acids. Even in the limestones and magnesian limestones its action is very slow and on granites it is so slow as to be practically negligible."

Through the kindness of Sir Frank Baines we have been able to reproduce five out of a very large number of photographs, illustrating the process of disintegration which some of the most important historic buildings are undergoing through

the agency of smoke and the acid gases of burning coal. (See Plates I, XI and XII.)

In the further course of his address, referring to the cost entailed, Sir F. Baines said :

"I have endeavoured to form an estimate to ascertain what proportion of these charges (*i.e.*, for maintenance and repair of historic and official buildings) can be regarded as due to the impurities in the atmosphere ; it is a difficult question ; but if the air were as clear and pure in towns as it is in the rural districts, I estimate that at the very least £120,000 per annum could be saved upon the maintenance of official buildings in the charge of my Department. This computation cannot, of course, be regarded as an exact figure ; it can only be an approximation ; but after taking carefully into account all the conditions and the appraisement of the serious depreciation of the buildings over the whole area of maintenance and repair work, the saving in annual charges might well be found to be from 30 to 40 per cent. of the present day costs."

3. Effects of Sulphuric Acid on Metal Work

We are indebted to Mr. W. B. Worthington, formerly chief engineer of the Midland Railway, and Mr. A. Rattray, formerly chief engineer of the Lancashire and Yorkshire Railway, for the details of experiments made to ascertain the loss of weight of rails arising from wear and tear, and from corrosion. A number of rails were placed in suitable positions by the side of the line, and weighed at intervals, and the loss of weight recorded. The rails were of the ordinary railway section, weighing about 86 lbs. per yard. The annual loss of weight from corrosion was as follows :—

	Loss of weight in pounds per annum per yard.	Number of years over which observations extended.
(1) In the centre of the town . . .	1·04	17
(2) In a dry place in a smoky tunnel .	1·48	13
(3) In a wet place in the same tunnel	1·71	8
(4) On the sea coast amongst sand hills	0·18	17

The effect of smoke is very evident both in the town and in the tunnel. It would appear that the amount of corrosion due

1 part per 100,000. 4 parts per 100,000. 16 parts per 100,000.

FIG. 1.—Effect of various proportions of sulphuric acid in water.

2 parts per 100,000. 8 parts per 100,000. 32 parts per 100,000.

FIG. 2.—Effect of various proportions of sulphuric acid in water.

Garforth rain neutralized. Garforth rain. Leeds rain.

FIG. 3.—Effect of (1) Garforth rain-water neutralized; (2) Garforth rain-water; (3) Leeds rain-water.

FIG. 1.—Effect of various proportions of sulphuric acid.

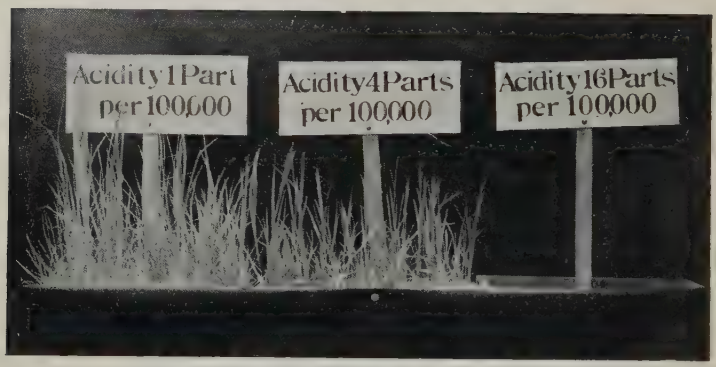


FIG. 2.—Effect of various proportions of sulphuric acid.

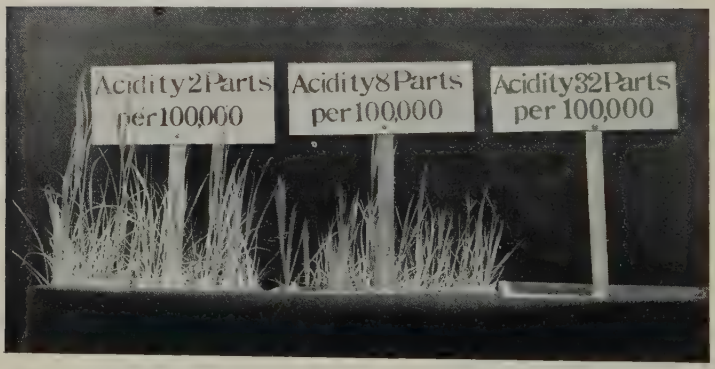


FIG. 3.—Effect of various proportions of sulphuric acid.

to this cause from town air is more than six times that from the purer atmosphere of the sea coast. This action on rails must, of course, be the same for all ironwork exposed to the atmosphere, and gives an indication of the widespread amount of corrosion which must be taking place.

4. Effects of Sulphuric Acid on Vegetation [1]

In order to examine the effect of sulphuric acid upon vegetation, Timothy grass (a perennial grass) was sown on May 12, 1908, in boxes 1 foot square, filled with soil from a well-mixed heap, and treated exactly alike throughout the experiments with the exception of the watering. They were watered at rates corresponding to the average Garforth rainfall of 25 inches, with waters containing respectively 1, 2, 4, 8, 16, and 32 parts of sulphuric acid per 100,000. Other boxes were watered with Garforth rain-water, with the same water neutralized, and with Leeds rain-water. It may be added that the acidity of the Leeds rain ranges from $\frac{1}{2}$ to occasionally 10 parts per 100,000.

In the case of the Leeds rain-water and of those waters containing the higher degrees of acidity, germination was distinctly checked, and the delicate green of the young grasses quickly changed to a yellow or brown (Plate IX).

The grasses treated with water whose acidity was 32 parts per 100,000 were killed off in little more than three months, and not a trace of vegetation of any kind was visible in the following spring. The water of acidity 16 parts per 100,000 proved fatal in less than a year. The weights and composition of the material grown during the three seasons 1908–1910 are recorded in the table on the next page. In addition to the dry matter, the amounts of nitrogen and crude fibre (that is, the indigestible matter) have also been estimated.

It will be observed that in every case the yield steadily decreased with the increased acidity of the water used, and that the effects in this respect were cumulative.

In the first season only the " 32 parts " shows any decided fall in the yield. In the following season this specimen was

[1] Crowther and Ruston, *J. Agric. Science* (1911), **4**. 25.

killed, whilst the "16 parts" was *in extremis*, and in 1910 not a trace of vegetation was left; whilst the "4 parts" and "8 parts" show a minimal yield. Even the grass in the "2 parts" box is suffering severely, and, most interesting of all, the Leeds rain is now definitely telling its tale.

The Action of Sulphuric Acid on the Yield of Timothy Grass.

Description of water used.	Total dry matter.			Nitrogen in dry matter.			Crude fibre in dry matter.		
Year	1908	1909	1910	1908	1909	1910	1908	1909	1910
	gms.	gms.	gms.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Garforth rain, neutralized	28·0	24·9	14·7	2·47	2·22	1·58	24·3	21·9	23·7
,, ,, ordinary .	24·8	18·5	11·0	2·01	1·75	1·54	25·9	25·3	26·0
Leeds rain	23·8	17·5	6·6	1·96	1·42	1·23	26·4	26·3	27·2
1 part H_2SO_4 per 100,000	30·5	18·2	12·0	1·89	1·61	1·40	25·5	27·3	26·2
2 parts ,, ,,	28·7	17·8	8·0	1·84	1·06	1·09	26·3	28·8	28·7
4 ,, ,, ,,	28·8	10·0	3·9	1·74	0·95	0·86	27·4	28·9	28·9
8 ,, ,, ,,	24·8	8·2	3·7	1·77	0·89	0·82	28·2	33·4	30·3
16 ,, ,, ,,	23·8	1·8	nil	1·62	0·87	—	30·8	36·2	—
32 ,, ,, ,,	14·1	nil	nil	0·93	—	—	31·6	—	—

The three photographs reproduced in Plate X show the appearance of the grass after the first season's growth, the boxes being arranged in order of increasing "parts" of sulphuric acid.

The results of the analyses also show that the increase in acidity, besides reducing the total yield of dry matter, lowered the nitrogen content and increased that of crude fibre. The grass grown with the nine acid waters must obviously be greatly inferior in nutritive value to that grown with neutral or less acid waters. The effect is quite evident in the case even of the grass watered with water containing only one part of acid per 100,000, a proportion which is about the average in Garforth rain, and hence it becomes a matter of importance to ascertain to what extent this deterioration can be traced to the soil of meadows in smoke-infected areas. The soil in the boxes was

therefore submitted to chemical and bacteriological examination by well-known methods.[1]

Chemical Analysis of Soils.

	Nitrogen.			"Available" P_2O_5 (Dyer).	"Available" K_2O (Dyer).	Total carbonate expressed as $CaCO_3$.	Oxygen absorption (Russell and Darbishire).
	Total.	As Ammonia.	As Nitrate.				
	per cent.	per million	per million	per cent.	per cent.	per cent.	mm.
Garforth rain, neutralized .	0·179	3·5	5·8	0·014	0·012	0·23	12
„ „ ordinary .	0·159	1·4	4·7	0·019	0·019	0·18	9
Leeds rain „ .	0·162	2·5	3·7	0·026	0·031	0·14	5
1 part H_2SO_4 per 100,000	0·154	2·1	4·1	0·023	0·015	0·16	8
2 parts „ „	0·158	4·9	3·3	0·026	0·021	0·12	6
4 „ „ „	0·128	6·8	1·3	0·026	0·026	0·10	4
8 „ „ „	0·126	7·9	0·5	0·041	0·029	0·05	4
16 „ „ „	0·144	8·1	0·0	0·043	0·042	0·04	3
32 „ „ „	0·133	9·4	0·0	0·046	0·043	0·03	0

With the exception of the total nitrogen, a distinct correlation is traceable in all cases between the amount of acid applied to the soil and the different quantities estimated. Thus, increasing acidity has clearly led on the one hand to diminished content of nitrates and of carbonates, and to diminished absorptive power for oxygen, but on the other hand to increased content of the easily soluble mineral ingredients and also of ammonia. The absorptive power for oxygen thus measured is in effect a measure of the activity of the micro-organisms in the soil, and this diminished absorptive power is a clear index of the general diminished fertility of the soil.[2] The increase in the ammonia-content of the soil with increased applications of acid finds a ready explanation in the results of the bacteriological investigations.

[1] The methods used were those of Kjeldahl-Gunning for nitrogen, Russell for ammonia, Dyer for phosphoric acid and potash, Amos for total carbonate, Russell and Darbishire for absorptive power for oxygen, and nitrates were determined by extraction and reduction to ammonia.

[2] Russell and Darbishire, *J. of Agric. Science* (1905), **1**. 260.

Bacteriological Investigation of Soils.

	Total number of bacteria per gm. of dry soil.	Ammonia produced from peptone.	Ammonia converted into nitrates.	Nitrogen fixed per gm. of mannite.
	thousands.	mgs.	mgs.	mgs.
Garforth rain, neutralized	5228	13·9	1·02	4·6
„ „ ordinary	1690	12·7	0·84	3·7
Leeds rain „	1170	11·7	0·73	3·0
1 part H_2SO_4 per 100,000	1260	12·1	0·80	3·3
2 parts „ „ „	1100	11·2	0·85	3·0
4 „ „ „ „	690	10·5	0·52	2·8
8 „ „ „	130	10·3	0·36	2·4
16 „ „ „	40	10·3	0·28	1·9
32 „ „ „	15	8·1	0·13	1·8

The influence of the treatment with acid upon the extent and character of the bacterial flora of the soil will be seen to have been very striking, the total number of bacteria diminishing rapidly with increasing acidity, this being reflected also in diminished activity as regards ammonia-production, nitrogen-fixation, and, above all, nitrification.

Ammonia-producing Bacteria.—The activity of these bacteria was measured by their effect upon peptone. The procedure in each case was to incubate $1\frac{1}{2}$ grams of the soil with 100 c.c. of a nutrient solution containing 1 per cent. of peptone, but no other source of nitrogen. The incubation at 30° C. was prolonged for three days and the ammonia produced then estimated by distillation with magnesia. In each case a strong growth was obtained at the surface of the peptone solution, but the rate of development and appearance of the film varied so markedly in the different flasks as almost to permit the soils to be graded on this basis alone.

It will be noted that whereas ammonia-production was appreciably more active in the " Garforth Neutral " soil than in those which had received acid waters, the diminution of activity with increasing acidity was very gradual and slight, being only about 25 per cent. less, even in the " 16 parts " soil. There was, however, a marked falling off in the case of the " 32 parts " soil.

Nitrification.—The most marked effect of the acidity is seen in the reduced activity of the nitrifying or nitrate-producing organisms.

This was investigated in each case by incubating 5 grams of the soil with 100 c.c. of a sterile nutrient medium containing 0·05 gram of ammonium sulphate, 0·5 gram of calcium carbonate being also added. After 21 days' incubation at 30° C. the nitrates formed were estimated colorimetrically by the picrate method. The films obtained were in no case very well developed, which was not surprising in view of the initial poverty of the soil in calcium carbonate. The amounts of nitrate produced were thus in all cases very low, but still the influence of acidity is brought out very sharply (Fig. 11). There is again the general concordance between the results

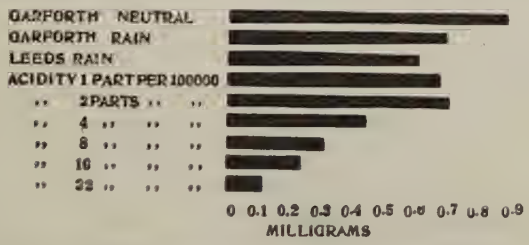


FIG. 11.—Influence of acidity. Nitrogen nitrated.

obtained with the two ordinary rain-waters and the " 1 part " and " 2 parts " soils.

It will be noted that the activity of the nitrifying organisms was inhibited to a relatively far greater extent than that of the ammonia-producing organisms. Thus, for instance, in the " 4 parts " soil the nitrate-production was only one-half, whereas the ammonia-production was fully 75 per cent. of that in the " Garforth Neutral " soil. This furnishes a ready explanation of the fact, previously recorded, that the ammonia-content of the soils was greater when increased amounts of acid had been applied to them (p. 55).

The conversion of the complex albuminoids originally present in the soil into the soluble nitrates upon which the plant principally feeds, proceeds in at least two stages. The organisms which are responsible for the first change from albuminoids into ammonium compounds are apparently

susceptible, though not vitally so, to acid influences. On the other hand, the organisms which are responsible for the final change of the ammonium compounds into nitrates are practically unable to work in the presence of free acids. Hence, though the activity of the ammonia-producing organisms is distinctly checked, ammonia is still produced. In the case of the higher degrees of acidity the nitrifying organisms are almost non-existent. Thus, the increased application of acid gives an increased ammonia content to the soil, not because more ammonia is produced, but because the smaller amount of ammonia thus produced is incapable of being converted into nitrates, and hence accumulates.

Nitrogen-fixing Organisms.—The activity of these organisms was measured by incubating 1 gram of soil with 0·5 gram of calcium carbonate and 100 c.c. of a sterile nutrient solution containing 2 grams mannite, 0·02 gram each of potassium dihydrogen phosphate, crystallized magnesium sulphate, and sodium chloride, and 0·1 gram of calcium sulphate. After incubation for 13 days at 30° C. the nitrogen-content of the mixture was determined by the Kjeldahl-Gunning method. The amount of nitrogen fixed was then arrived at by deducting the nitrogen originally present in the 1 gram of soil taken.

The characteristic growth of the nitrogen-fixing organisms has been fully described by Ashby, and the sequence of gas-production, growth of film, and gradual darkening in colour referred to by him were exactly reproduced in these cultures.

The differences in the rate of development with the different soils were, however, so marked that it was quite possible from the appearance of the cultures to place the soils substantially in the order which was subsequently found to be that of their nitrogen-fixing activities.

Here again, as in the case of nitrification, the application of acid waters to the soil is seen to have exercised a marked inhibitory effect upon the activity of the nitrogen-fixing organisms, the reduction in the case of the soil on which the more impure rain-water (Leeds) was used amounting to practically one-third of the nitrogen-fixing activity of the " Garforth Neutral " soil (Fig. 12).

It is also interesting to note that here again, as in the case of the other forms of bacterial activity investigated, the Leeds

rain-water exercises an inhibitory effect somewhat greater than that of water containing one part of H_2SO_4 per 100,000, but not greater than that of water containing two parts of H_2SO_4 per 100,000. This accords precisely with the indications of the yields of dry matter and with the results of the analyses of Leeds rain samples recorded in p. 42.

To sum up, the presence of free acid in the atmosphere exercises a detrimental influence upon plant growth by direct action upon the leaves, and by indirectly reducing the activity not only of the necessary ammoniacal fermentation of the soil humus, but even more by lowering the activity of the nitrifying and nitrogen-fixing organisms in the soil. Moreover, the continued application to the soil of acid rain produces a grass distinctly poorer in protein and richer in fibre, and consequently less nutritious.

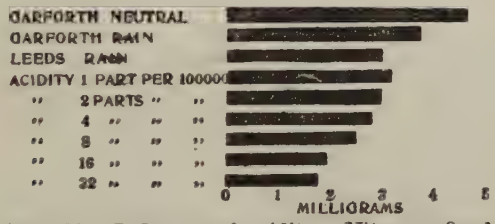


FIG. 12.—Influence of acidity. Nitrogen fixed.

The presence of smoke contamination is usually made manifest by an increased sulphur content in the leaves of trees and plants.

The following analyses by Mr. D. R. Steuart, of Broxburn, of the leaves of conifers illustrate this point very clearly.

Spruce Leaves.

Source of leaves.	[Percentage of SO_3 in original leaves.
1. Roman Camp, very near shale retorts	0·28 per cent. of total weight
2. Ecclesmachan, country village in neighbourhood of shale works	0·12 " " "
3. Near Dumfries, in open country	0·07 " " "

Scotch Fir.

1. Roman Camp . . . . . 0·19 per cent.
2. Near Dumfries . . . . . 0·06 „

In the case of leaves of the same age and from the same plant, collected from localities where sulphur content of the air has been determined, a striking correlation is observed between the SO_3 content in the dry matter of the leaves and the annual deposit of SO_3 from the air as previously determined.

Station.	Yearly deposit of SO_3 in lbs. per acre.	Percentage of SO_3 in dry matter of leaves.		
		Ash tree.		Lettuces.
		Total	After Cleaning.	
		Per cent.	Per cent.	Per cent.
1. Hunslet	215	4·52	3·15	3·22
2. Park Square . . .	197	4·16	—	2·61
3. University	134	—	—	1·99
4. Headingley Hill . . .	116	3·73	3·03	2·02
5. Weetwood Lane . .	98	3·52	2·27	1·53
6. Garforth	91	—	—	1·20

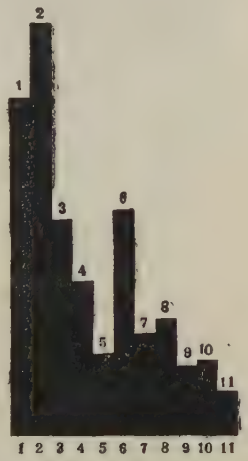
It would appear, therefore, that in the more smoke-infested areas, not only is there an increased deposit of sulphur compounds with the soot upon the surface of the leaves, but that there is also an increased intake of SO_2, probably through the stomatal openings.

5. Other Gaseous Products of Combustion and their Effects

Chlorides are found in large quantities in the atmosphere, especially in industrial areas, where, expressed as common salt, they sometimes reach as much as 100 to 130 tons per square mile of surface. The amount carried down by rain at the different stations previously referred to is shown in the

following diagram (Fig. 13) by means of the shaded columns. The actual quantities, together with the content of ammonia estimated in the same samples of rain, are given in the table at the end of this section.

That the greater part of these chlorides are purely local is proved by the following facts : They diminish rapidly in amount on passing northwards from the centre of the town. Thus at the Philosophical Hall they represent $21\frac{1}{2}$ tons per square mile ; one mile out they fall to $14\frac{1}{2}$ tons ; and two and a half miles out they fall again to 10 tons per square mile. Furthermore, the average chlorine content, as given by Angus Smith, of rain collected in inland country places in England is 3·88 parts per million, a figure practically identical with the average at Garforth, $7\frac{1}{2}$ miles distant. In an industrial centre like Hunslet the average rises to 35·43 parts per million, or nearly 10 times as much.



1. Leeds Forge. 2. Hunslet. 3. Beeston Hill. 4. Philosophical Hall. 5. Headingley. 6. Armley. 7. Observatory. 8. Kirkstall. 9. Weetwood Lane. 10. Roundhay. 11. Garforth.

FIG. 13.—Relative amount of chlorine.

An excess of chlorides taken alone is no proof of a bad atmosphere, for they naturally increase in quantity the nearer the vicinity to the sea ; but an excess in an inland district above the amount in the surrounding area is a clear proof of contamination from an industrial source. Of the 54 tons of chlorine per square mile deposited each year at Hunslet, 6 tons may be ascribed to the sea-spray, and the remainder to the impurities derived from blast-furnaces, glass-works, and potteries, as well as from the coal itself.

The nitrogenous impurities would all be distinctly beneficial to vegetation, either acting directly as stimulants and fertilizers or neutralizing the acidity due to the presence of sulphur or chlorine compounds. They are derived mainly from the nitrogen originally present in the coal, and also, in a smaller degree, from decomposing organic matter and from the

direct oxidation of free nitrogen of the air. In this case there does not appear to be the great variation in the amount in different parts of the town that is shown by other impurities, the highest representing 7 tons and the lowest 2½ tons to the square mile. It is, however, interesting to note that nitrogen, in the form of nitrates, is found only in the cleanest localities, and that the organic nitrogen is found in the largest quantities in the industrial areas.

1. Leeds Forge. 2. Hunslet. 3. Beeston Hill. 4. Philosophical Hall. 5. Headingley. 6. Armley. 7. Observatory. 8. Kirkstall. 9. Weetwood Lane. 10. Roundhay. 11. Garforth.

FIG. 14.—Relative amount of nitrogen.

The diagram of Fig. 14 represents, by vertical columns, the variation in the amount of nitrogen in the form of ammonia (black), organic nitrogen (shaded), and nitrates (blank), found in rain-water of the various stations.

The actual analytical results are shown in the following table:—

Chlorine and Nitrogen in Leeds Rain.

Tons per square mile.

Station No.	Chlorine.	Nitrogen			
		as ammonia.	as nitrate.	as albuminoid.	Total.
1	47·0	3·71	0·00	1·34	5·05
2	56·5	4·43	0·00	0·83	5·26
3	29·0	4·11	0·14	1·00	5·25
4	21·4	4·11	0·08	0·63	4·82
5	11·7	3·17	0·31	0·23	3·71
6	31·0	2·83	0·28	0·91	4·02
7	14·6	2·65	0·23	0·46	3·34
8	16·3	2·20	0·05	0·65	2·90
9	9·7	2·37	0·31	0·60	3·28
10	11·0	1·65	0·20	0·37	2·22
11	6·3	1·43	0·91	0·31	2·65

6. Arsenic in Coal, Soot, and Rain

Dr. Russell, in his exhaustive study of atmospheric impurities, already referred to (p. 40), had looked for and discovered arsenic in London rain-water to the extent of 0·0003 part per million.

It is well known that most kinds of coal contain small quantities of arsenic, probably due to the presence of arsenical pyrites. A large number of estimations of arsenic in coal were made in connection with the Royal Commission which inquired into cases of poisoning with beer containing arsenic.[1] In these analyses the quantity varied from a trace to 0·13 per cent. calculated as As_2O_3. In addition to this, Mr. T. Fairley, city analyst for Leeds, investigated household dust from different sources, and found the following quantities of arsenic[2] :—

	Per cent.
Dust from shelves, Mr. Fairley's laboratory . .	0·010
„ „ Mr. Mackey's „ . . .	0·011
Dust from bookcase, Mr. Fairley's office . . .	0·006
„ shop, Commercial Street, Leeds . .	0·004

We have been able to confirm Mr. Fairley's result in two specimens of dust, one taken from the top of a book-shelf near station 5 (Headingley), which contained a trace, and the other collected in the University (station 7), which consisted largely of soot, and contained 0·015 per cent.

There can be little doubt that the arsenic in the dust was present in the smuts from the coal.

Mr. Delépine,[3] in his evidence before the above Royal Commission, gave results of his examination of soot from various coals. In soot from South Yorkshire coals he found 0·08 per cent. of As_2O_3 ; in the soot from a coke stove burning coke from the Manchester gasworks, 0·4 per cent. was present ; in another soot from coke, about 0·5 per cent. He concluded that " the large amount of arsenic in soot causes a marked arsenical contamination of the air in Manchester, and may

[1] " Report of the Royal Commission on Arsenical Poisoning," Part I, 1901 ; Part II, 1902–3.

[2] *Ibid.*, Part II, p. 62.

[3] *Ibid.*, Part I, p. 195.

account for the bad effects of this air on vegetation." Further on he said: "I have a suspicion that soot from towns, where arsenical coal is used, is far more irritating to the lungs than pure coal dust. The reason why I say so is that I have noticed there is generally more fibrous tissue produced in the lung in town anthracosis than when the coal is inhaled as dust, as, for instance, in the case of coal-miners. I find the lungs of coal-miners may become as black as soot and all the lymphatic vessels entirely distended with ordinary coal dust without there being evidence of very distinct inflammatory reaction; whilst, on the contrary, in towns, where the amount of carbon collected in the lungs is smaller, there are frequently capsules of fibrous tissue in the lungs around small masses of carbon which have accumulated, indicating some irritating action on the part of the soot."

A large number of samples of soot have been examined by us for arsenic, which was found to be present in every case.[1] The following are the results calculated as As_2O_3:—

	10 ft.	15 ft.	20 ft.	25 ft.	30 ft.	35 ft.
Winston Gardens .	0·0021	0·0044	0·0056	0·0090	0·0053	0·0017

It is seen from these figures that the quantity increases to a maximum at 25 feet from the fire-grate and then diminishes. The result is what might be anticipated from the fact that arsenic readily sublimes both in the elementary state and as oxide, and would therefore pass from the hotter to the cooler part of the flue where the greater portion would deposit.

The same result was obtained in the case of soot collected at different heights from the boiler chimney of the Leeds University (per cent. of As_2O_3)—

	Coal.	Bottom of chimney.	3 ft.	13 ft.	Top of chimney 100 ft.
University chimney .	0·129	0·104	0·073	0·100	0·160

The cause of the increase in the amount of arsenic at the bottom of the chimney is not apparent, but it may possibly be due to local cooling. It is, however, noteworthy that the highest

[1] These analyses were performed by the Gutzeit method under our supervision by Mr. C. J. Smithells, a student of the Leeds University, to whom we offer our best thanks.

figure is obtained at the point where the soot escapes into the open air, and that the percentage is higher than in the coal used. It should be noticed, also, that the lower quality of coal used for the boilers is higher in its arsenic content.

Finally, the amount of arsenic has been estimated in a good quality of Yorkshire coal used for domestic purposes in which only a trace of arsenic was present. The soot in this case, collected near the bottom of the flue, contained 0·018 per cent.

It is an interesting fact that all town dust, as well as town air contaminated with soot, is never free from arsenic, and, according to Mr. Delépine, may affect detrimentally the health of the community.

TOWN FOG

Fog or mist consists of suspended particles of water. One curious and interesting feature about the formation of fine particles of mist or the larger particles we call raindrops or dew is that the starting-point, the nucleus of each of these particles of water, is a speck of dust—a speck which may be so minute as to be invisible to the naked eye. Particles of water may also be deposited on what are known as ions ; but this is an artificial condition of the air, which may be induced by radioactive substances and in other ways. Generally speaking, however, suspended particles of water in the air have a solid nucleus. Without dust there is no mist, rain, or dew. What would happen, then, if air free from dust were saturated with moisture and the temperature fell ? Water would be deposited, but only on solid objects. It would appear on the ground and on buildings. It would stream down the walls of our houses and soak the surface of the earth. Every solid thing out-of-doors would be wet, but no mist would appear and no rain would fall. As the number of these dust particles have a direct relation to the density of a fog, determinations have been made of the number in the air of Leeds at different centres on the same day by the use of an ingenious apparatus devised by Mr. John Aitken, F.R.S., and known as " Aitken's dust counter."

Dust Particles in Leeds Air.

Station No.	Locality.	Number per cubic inch.
7	Woodhouse Moor (N.W. wind) .	530,000
4–7	The University	852,000
4	Town Hall Square	1,238,000
2–4	Parish Churchyard	3,638,000
—	Glasgow (N.W. wind, Aitken) .	3,736,000

An ingenious modification of Aitken's dust counter has been devised by Dr. J. S. Owens to which the name *jet dust counter* has been given and is described in detail in the eighth annual report of the Advisory Committee on Atmospheric Pollution, 1921–1922, p. 34. Although the apparatus is not so compact or convenient for manipulating and for counting dust particles, as the particles are deposited on a cover glass they can be removed and examined microscopically at leisure. In this way some curious observations have been made on the nature of these atmospheric particles, which are recorded in the ninth Annual Report, p. 40, *et seq.*

The actual number of dust particles found during fog on two occasions was a little over 20,000 per c.c., and the highest number recorded during very dense fog was 53,000 per c.c.[1] whilst the number on fine days was below 1000 per c.c. Aitken's records for London are 48,000–150,000 and for Glasgow in a north-west wind 228,000. Our numbers by reference to the table will be seen to vary according to the proximity to the centre of the town from 32,400 on the outskirts to 222,000 in the centre on a clear sunny day with a north-west wind. The number found in the laboratory of the University of Leeds during a busy day increased from 200,000 in the morning to 400,000 towards the end of the afternoon. From these figures it would appear that Dr. Owens' counter gives results which are much lower than those recorded by Aitken's dust-counter. This has been attributed to the deposit of drops on electrically charged gases which would therefore be included among the solid particles. On the other hand, by the method of counting visible particles on a glass slip even under a powerful microscope ultra microscopic particles might well be overlooked.

The formation of mist or fog is necessarily connected with fall of temperature, but this fall may have a different origin in different cases. One well-recognized cause of fog formation is cooling of the air near the ground by radiation at the surface ; but there is another and frequent cause, as one of us has shown,[2] namely, by contact of a descending flow from higher ground of

[1] Report of the Advisory Committee on Atmospheric Pollution, 1922–23, p. 39.

[2] J. B. Cohen, "One Cause of Mist Formation," *Quart. J. Roy. Met. Soc.*, vol. xxx, p. 211.

cool air coming in contact with a warm, saturated layer lying above a moist surface, and may be called, in contradistinction to " radiation or cold-surface fog," a " contact fog." Again, a fog formed in one locality may drift into another, and this form has been termed a " cloud fog." To these three classes Mr. Lempfert, of the Meteorological Department, has added a fourth, or " smoke fog," which is caused by an accumulation of products of combustion in the atmosphere of large towns in dry, calm weather, so as to produce the appearance of fog.[1] According to this observer, the phenomenon known as " high fog," where the fog is confined to an area some distance above the level of the ground, can also occur under a variety of circumstances.

Of the 39 fogs recorded in London from September 1, 1902, to March 31, 1903, 27 were radiation and contact fogs, 4 were cloud fogs, and 8 were smoke fogs, that is, 20 per cent. of London fogs were artificially induced and preventable.

Without discussing at greater length the cause or character of fogs, let us turn to the effects of a town fog.

Fog is usually accompanied by a high barometer, a calm atmosphere, and a fall of temperature. Under these conditions a film of water coats every little floating particle of dust, which, heavily weighted with its unwonted cloak of moisture, has its progress impeded, hangs or falls, but does not rise, and, in its turn, impedes the movement of the air. Stagnation of the atmosphere is produced, and there occurs an accumulation of products of combustion, namely, carbonic acid, sulphurous and sulphuric acid, and soot, which under ordinary conditions are to some extent dispersed. Our senses give us abundant evidence of soot and sulphurous acid. Our faces and clothes are soon begrimed, and eyes and throats suffer from the irritating effects of the acid. The increase of carbonic acid in London air during fog has been determined by Dr. W. J. Russell,[2] who made frequent observations throughout the years 1882 and 1883. Taking 3·5 parts per 100,000 as the maximum amount

[1] A very complete account of the character and frequency of London fogs is given by Mr. R. G. K. Lempfert, of the Meteorological Department (see Blue Book, 1904, No. 160, on London Fogs), and by Captain A. Carpenter, R.N., on London Fog Inquiry, 1903.

[2] Monthly Weather Report of the Meteorological Office for April, 1884.

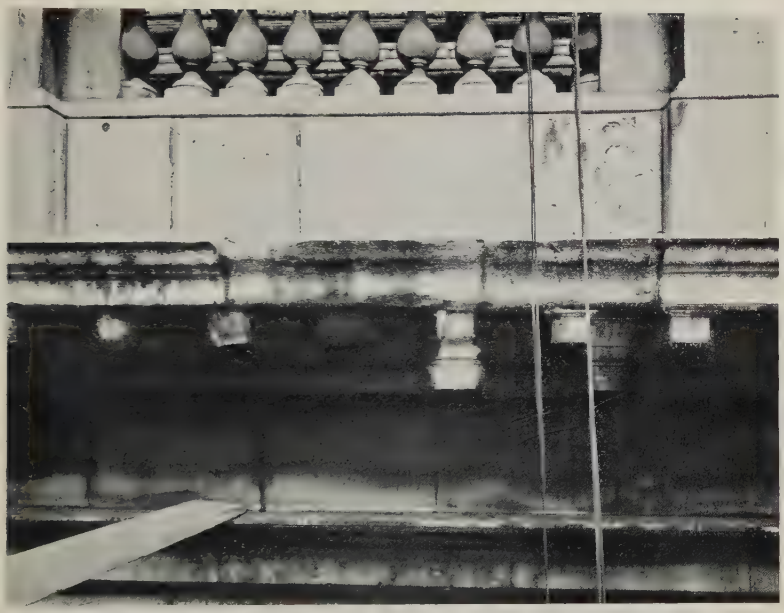


FIG. 1.—Somerset House : Quadrangle.
Portland stone cornice, showing decay and sooty incrustation.
(*Photo taken May* 13, 1920.)

FIG. 2.—Houses of Parliament : Cloisters.
Caen stone plinth showing exfoliation and serious decay.
(*Photo taken May* 10, 1920.)

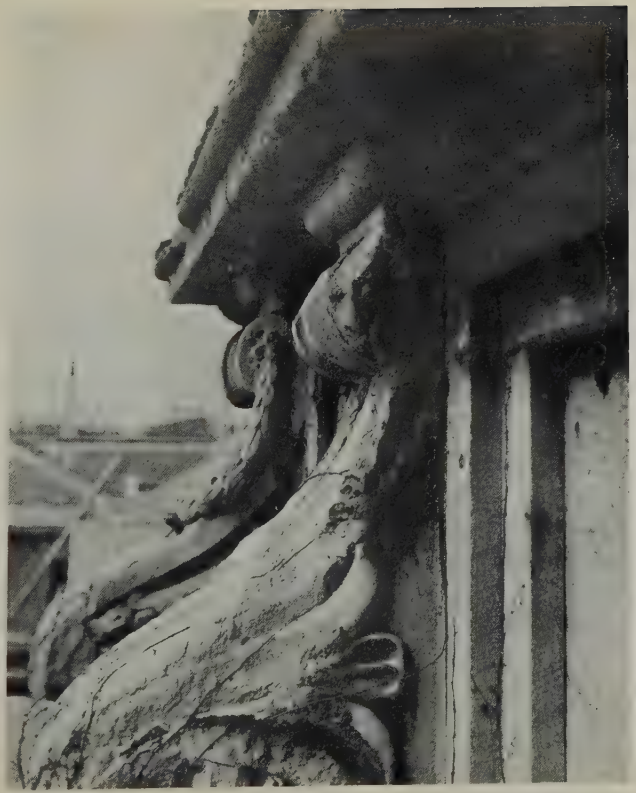


FIG. 1.—Buckingham Palace.

Bath stone in pediment, East gallery, Royal Mews. S.W. surface about 40 ft. above ground.

FIG. 2.—Hampton Court Palace.

Portland stone Balusters on N. side of Fountain Court. South aspect about 40 ft. above ground.

of carbon dioxide in pure country air, the following results were recorded during mist and fog :—

Date, 1882.	Weather.	Vols. of CO_2 in 10,000 air.	Temperature °C.		Barometer mm.	Direction of wind.
			Wet bulb.	Dry bulb.		
Jan. 17	Dense black fog . .	6·7	—	10·0	786	S.
„ 18	„ „ . .	5·7	—	4·0	786	S.
„ 19	Slight white fog . .	4·8	—	6·0	768	S.
„ 25	Dense black fog . .	10·5	—	3·5	780	S.
Feb. 3	Slight fog	6·9	3·0	4·4	781	S.
„ 4	Dense black fog . .	10·7	4·0	5·0	785	S.
Mar. 15	Slight white fog . .	5·6	9·0	11·0	775	S.E.
Oct. 26	White fog	9·9	0·6	7·7	750	W.
Nov. 18	Dense black fog . .	9·6	2·2	2·7	760	S.E.
Dec. 1	Thick white fog . .	5·5	1·6	2·2	765	S.
„ 2	Slight mist . . .	5·1	1·1	1·6	766	S.E.
„ 10	Thick white fog . .	9·4	0·5	1·1	755	S.W.
„ 11	„ „ „ (noon)	11·0	0·0	0·5	755	S.W.
„ 11	„ „ „(5p.m.)	14·1	0·0	0·5	755	S.W.
„ 14	White fog, slight . .	6·2	4·4	4·4	755	S.E.
„ 15	„ „ „ . .	5·4	5·0	6·1	753	S.E.
„ 15	Overhead fog, white .	4·8	3·3	4·4	760	S.E.
„ 20	Dense black fog . .	8·1	4·4	4·7	767	S.

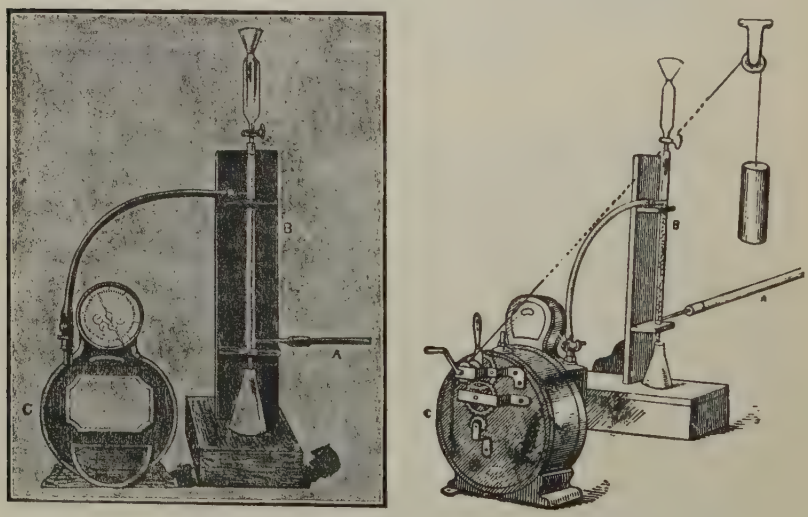
"The largest amount of carbonic acid found was 14·1 parts; this was on December 11, 1882, and was during a long-continued fog. On referring to the table it will be seen that the fog had begun on the previous day, when there was a 'thick white fog,' and the carbonic acid had then increased to 9·4; at noon on the 11th there were 11·0 parts, and at 5 p.m. the carbonic acid had increased to 14·1 in 10,000 of air, that is, there was more than $3\frac{1}{2}$ times the normal amount present. Supposing, then, this had been an increase of only pure carbonic acid, such a change in composition of the atmosphere would be felt by most people, but an accumulation of carbonic acid means, certainly, a very large accumulation of other bodies, which probably are more, rather than less, deleterious than carbonic acid itself."

This statement, which Dr. Russell has appended to his

observations, is entirely supported by the results of experiments on sulphurous acid found in town air during fog.

Before, however, referring to the other and more deleterious accompaniments of fog, the following data of the amount of carbonic acid in the air obtained by Dr. Russell shows how rapidly the air assumes its normal condition when the fog clears :—

1884.	Vols. of CO_2 per 100,000 air during fog.	Vols. of CO_2 per 100,000 after fog had cleared.
October 26 . . .	9·9	5·0 after 2 hours
November 18 . .	9·6	5·0 ,, 1½ ,,
December 1 . . .	5·5	4·1 ,, 4½ ,,
December 20 . . .	8·1	5·2 ,, 1½ ,,
1884.		
October 11 . . .	7·6	5·1 ,, 5 ,,
April 27	5·3	4·6 ,, 2½ ,,



Figs. 15, 16.—Apparatus for estimating sulphurous acid in air.

The apparatus for estimating sulphurous acid in air, which was devised by one of us in connection with experiments instituted in Manchester in 1891 on behalf of the " Air Analysis Committee ", of the Manchester Field Naturalists' Society,

is shown in Figs. 15, 16. It consists of a long glass tube, A (about $\frac{1}{2}$ inch in diameter, open at both ends), which is fixed horizontally so as to project into the open air and a glass tower B, about 30 inches high and $1\frac{1}{4}$ inches in diameter, open at the top and drawn out into a fine jet at the bottom. Two side tubes are fixed to the tower, one near the bottom and the other on the opposite side near the top. The tower is filled to within 1 inch of the upper side-piece with glass beads, and into the open top a tap-funnel is inserted through a tightly fitting cork. The lower side tube is attached to the horizontal tube ; the upper one, by means of a wide india-rubber tubing, to a combined meter and aspirator, C. This is an ordinary wet meter converted into an aspirator by attaching toothed wheels to the revolving drum, and driving the wheels by means of a wire cord passing over a pulley and carrying a weight. A series of dials register the volume to $\frac{1}{100}$th of a cubic foot. The method of conducting the experiment is as follows : About 250 c.c. of a solution of hydrogen peroxide in water containing about 1 mgrm. of active oxygen in each c.c. is poured into the tap-funnel, from which it is allowed to drop on to the glass beads at the rate of about 1 drop a second. The liquid passes down and out at the constricted end of the tube and falls into a flask placed below. A drop of liquid permanently fills the jet and seals it effectually from the entrance of air from the interior of the room. After running through, the liquid is poured back into the funnel and passed through again. The weight being wound up, the volume indicated on the dial is read off and the drum set in motion. With a column of beads of about 20 ins. and a weight of 20 lbs., 20 cubic feet can be aspirated in an hour. Once started the apparatus needs no further supervision until either the weight has reached the ground or the solution of hydrogen peroxide has run out of the funnel. The period required for this is readily determined, so that no time is lost in looking after the apparatus.

The following tables contain the results of numerous observations of the sulphurous acid in the air. The first gives the average amount of sulphurous acid in Manchester air during four months of 1892, and the second the amount in the outskirts and centre of the town.

Sulphurous Acid in Manchester Air.

Milligrams of SO_3 per 100 cubic feet.

Month.	Minimum.	Maximum.	Average.
September	0·7	3·5	1–2
October	0·7	6·0	2–4
November	2·0	12·0	6–8
December	3·0	30·0	6–10

Milligrams of SO_3 per 100 cubic feet.

Date.	Outskirts.	Centre.
September 5	0·7	1·8
October 14	0·8	3·5
November 5	1·7	4·9
„ 10	2·5	4·1
„ 13	3·3	7·6
„ 17	2·0	5·9
„ 19	2·9	8·4
„ 22 Fog	4·2	9·7
„ 27 Fog	9·3	15·7
December 17	2·3	9·2
„ 21 Fog	16·5	32·2
„ 22 Fog	12·7	22·6
„ 23 Fog	12·7	25·8

Thus we see that both carbonic acid and sulphurous acid, as might be anticipated, rapidly increase during fog. That the amount of soot increases *pari passu* scarcely requires proof. The condition of one's face and clothes and household fabrics during dense fog, and the black, slimy deposit which is seen to cover the ground after the air has cleared, are sufficient evidence of this accumulation. An attempt to estimate this deposit by collecting it on glass plates was frustrated by the fortunate absence of fogs in Leeds when the plate experiments were in progress (see p. 21).

On January 27, 1909, there was, however, a dense fog, accompanied by a heavy deposit of hoar frost. A large amount of the latter was collected in the neighbourhood of station 5, melted, and analysed. To compare the amount of impurity with that of normal rain, the average composition of rain of the year, which fell at the same station, is given in the following table :—

Rain and Hoar Frost at Station 5 (Headingley).

Parts per million.

	Suspended matter.	Tar.	Ash.	Acidity.	Sulphur.			Chlorine.	Nitrogen.		
					as SO_3.	as SO_2.	Total		as NH_3.	as N_2O_5.	as albuminoid
Average rain	115	15	28	1·9	22	5·7	27·7	7·3	1·98	0·196	0·434
Hoar Frost	4620	158	67	102·9	148	41·0	18·9	94·6	8·57	0·0	1·618

The hoar frost contained forty times as much soot as the average rain, and one hundred times the acidity. The photograph (shown in Plate II, Fig. 3), gives the appearance of (I) rain-water, (II) melted snow before the fog set in, (III) melted snow after the fog dispersed.

There is another record of some interest which may be quoted here. "During the last fortnight in February, 1891, the previously washed roofs of the glass-houses at Chelsea and Kew, the former just within and the latter just outside London, received a deposit from the fog amounting to 6 tons to the square mile," [1] or eight times the average daily deposit in Leeds. This soot had the following composition :—

Substance.	Chelsea.	Kew.
	Per cent.	Per cent.
Carbon	39·0	42·5
Hydrocarbons	12·3	4·8
Organic bases	2·0	—
Sulphuric acid	4·3	4·0
Hydrochloric acid	1·4	0·8
Ammonia	1·4	1·1
Mineral matter	33·8	41·5
Water (by difference)	5·8	5·3

Even in a country district like Garforth, which is subject to

[1] Hon. R. Russell, *London Fog and Smoke*,

some atmospheric contamination from a neighbouring colliery as well as from the more distant smoke of Leeds, a considerable increase in the impurities occurs in time of fog. The following statistics have been selected from the analyses of Garforth rain during the winter of 1908–1909 on dates when fogs occurred, and for comparison the average impurities for the two years 1907–1909 are given on the last line of the table.

Influence of Fog—Analysis of Garforth Rain.

Parts per million.

Date.	Nitrogen as NH_3.	Nitrogen as N_2O_5.	Nitrogen as albuminoid.	Total	Cl.	SO_3.	SO_2.	Acidity as H_2SO_4
1908.								
Oct. 21	2·462	0	0·865	3·327	1·33	17·18	7·79	15·80
Nov.	3·214	0	0·276	3·490	6·14	19·47	6·64	7·97
Dec.	4·178	0	1·236	5·414	11·12	29·08	6·64	41·37
Dec.	2·472	0	0·096	2·568	5·88	16·26	0·0	11·16
1909.								
Jan.	1·186	0·528	0·536	2·250	21·75	10·66	4·68	4·40
Average 1907–09 .	1·10	0·33	0·24	1·67	3·38	11·43	3·48	3·49

Dr. Russell[1] has estimated the solid organic impurities in the air during fine, dull, and foggy weather in 1883 to 1885, and, although no experiments were made in dense fog, the results are sufficiently suggestive, the average amount in 1000 cubic feet of air being as follows :—

	Grams per 1000 cubic feet of air.
Fine weather	0·0035
Dull „	0·0103
Foggy „	0·0244

from which it is seen that with only slight fog the amount of soot increases seven times. If the ratio increases with that of the

[1] "On the Impurities in London Air," *The Monthly Weather Report of the Meteorological Office for August*, 1885.

other products of combustion (carbonic and sulphurous acid), it would be four times as compared with the carbonic acid and fourteen times as compared with the sulphurous acid. It must be remembered, however, that these two products are gaseous and therefore diffuse, and moreover that the sulphurous acid is much more soluble in water than the carbonic acid, which will explain the larger increase of the former. That the increase in the amount of soot must necessarily be much greater than that of the sulphurous acid follows from the fact that being solid it cannot escape by diffusion. There is one other point to be considered. If we assume dust particles to form the solid nucleus upon which the moisture is precipitated, then it might be supposed, from the denseness of fog depending upon the number of these particles, that the fog must be thicker in the town than in the country. The very large number of these particles distributed everywhere, even over the sea, is, however, more than sufficient to produce the densest fog, and according to the Hon. Rollo Russell,[1] the dense fogs of towns cannot be ascribed to this cause. But each particle of water floating as fog becomes coated with a film of sooty tar. Evaporation is thus retarded, and a fog once formed is liable to persist longer than if these particles were composed of pure water. The black surface of each particle of water will lose heat more quickly than a correspondingly clean particle, and also help to retard its dispersion. Whether, as sometimes alleged, smoke may actually originate, as well as aggravate, a fog is still an open question ; but the evidence seems on the whole to be opposed to this idea.[2]

The blackening of silver and copper articles, which is so noticeable during foggy weather in town, is due to a thin film of the black sulphide of the two metals ; but is not produced by either sulphurous or sulphuric acid. It may, however, be caused by sulphur disseminated as sulphide in the soot, or by hydrogen sulphide contained in the products of combustion of coal. In order to ascertain the amount of sulphur in soot, we have estimated the quantity in the various samples referred to on p. 7 with the following results :—

[1] *London Fog and Smoke.* London : P. S. King & Son. 1905.

[2] Dr. W. N. Shaw, Address on Fog, *Coal Smoke Abatement Conference*, 1905.

Percentage of Sulphur in Soot.

Source of sample.	Base of chimney.	Top of chimney.
Soot from brass foundry	2·23	4·36
North Grange Mount, study flue .	2·32	—
,, ,, kitchen . .	1·46	—
The University, fireplace	2·99	—
,, boiler	2·76	2·84
Winston Gardens, dining-room . .	2·18	2·45
,, kitchen . . .	2·20	—

THE DISPERSAL OF SOOT

It would be an interesting point to discover to what extent outlying districts participate in the atmospheric contamination produced in an industrial centre. It is an easy matter to detect the presence of soot at a distance of many miles from its origin, though the quantity falls away rapidly, and it will probably only be the finest particles which travel any distance. That such particles may travel as much as 60 miles is proved by the deposition of salt crystals observed by one of us in the neighbourhood of Leeds after a strong south-westerly gale. These salt crystals could only have been deposited from spray blown across from the Irish Channel. But there is another way in which soot is conveyed long distances, namely, by rain-clouds traversing an industrial area and absorbing, like fog, the solid and gaseous products of combustion. Where the cloud discharges a very visible fall of soot occurs. This phenomenon is not by any means uncommon. In the Lake District such deposits brought down by rain are frequently observed. A rain cloud charged with soot, when it breaks above a sheet of water, produces a characteristic chequered appearance on the surface, which is due to the tarry matter spreading out into patches. When the rain ceases these black greasy patches are blown shorewards and form a fringe of black scum (Plate XIII, Fig. 2). An examination of this scum clearly reveals its origin. The same thing has been noticed on snow on the hills of the district, especially when on the melting of the snow the black particles collect, leaving dark patches of soot on the grass. Putting the facts together, it may be safely inferred that nowhere, at least in the North of England, is the country free from atmospheric contamination from smoke.

THE PLANT AS AN INDEX OF SMOKE POLLUTION

In the earlier chapters an account has been given of investigations carried out as to the nature and extent of atmospheric pollution by coal smoke in and near an industrial town. These investigations were at first limited to the area within three miles' radius of the centre of Leeds. Later, subsidized by a Government Grant from the Development Fund, they were extended to cover a wider area.

The information thus obtained, as to the relative freedom or otherwise of the various districts from pollution by coal smoke, has been exceedingly valuable in studying not only the effects of that pollution on plant life, but also the ways in which the plant itself may be used as an index of the amount of that pollution.

1. In the first place the *General Type of Vegetation* in the smoke infested areas is instructive in drawing broad conclusions as to the amount of smoke pollution.

Certain plants have been found to be resistant, and others particularly susceptible to smoke damage; and the presence or absence of some of these "Test Plants" is certainly suggestive.

The evergreens, which have to withstand the winter smoke, are specially susceptible. Many of these in a smoke infested area are quickly killed; others first become deciduous and then finally disappear. Among the evergreens, the privet is particularly interesting, as can be seen from the notes summarized in the following table.

District.	Annual Deposit of Soot in tons per sq. mile.	Observations with regard to the Privet.
3 miles to the north of Leeds	29	Evergreen and flowers.
2 miles to the north of Leeds	42	Evergreen, but does not flower.
1 mile to the north of Leeds .	114	Few leaves only retained through the winter.
Centre of city	243	Leaves fall in January.
Industrial Leeds	539	Leaves fall in November.

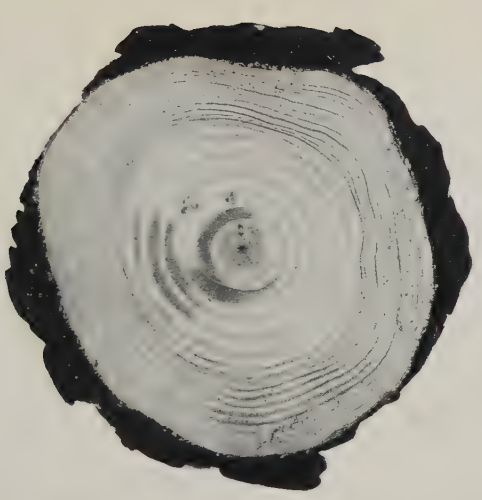
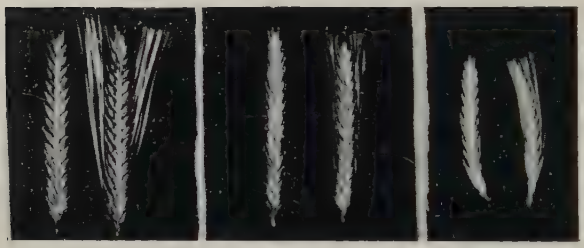


FIG. 1.—Section through stem of Scotch fir.

FIG. 2.—Black fringe of soot on Coniston Lake; Lake District.

Adel. Weetwood.



Headingley. University. Hunslet.

FIG. 1.—Photographs of wheat and barley grown in different localities.

Adel. Weetwood. Headingley. University. Hunslet.

FIG. 2.—Photographs of oats grown in different localities.

In Park Square, near the centre of the city, the laurel, aucuba, and rhododendron are deciduous ; while in Hunslet, the heart of industrial Leeds, even the box becomes deciduous, and the laurel is killed off in about two years.

Of the evergreens, the most susceptible are the conifers. These trees are Xerophytic ; their natural habitat is in a pure atmosphere at a high altitude, where the winds are high and the barometic pressure low, and where consequently evaporation from the leaf surface will be great. The soil, however, will be shallow and the roots none too plentifully supplied with moisture ; hence there will be a constant necessity to husband the water supply as far as possible. This end has been effected in the evolution of the plant by the development of small leaf surface, and sunk stomata. Both of these characteristics, while useful in the natural habitat of the conifers, prove their undoing in a smoke-infested area. Conifers planted in Hunslet we have seen killed off in less than three months. Twelve years ago, more than twenty conifers were planted in the grounds of the Leeds University, one mile north from the centre of the city. At the end of three years not one was alive. The only two localities in Leeds in which conifers attain even a moderate growth are Roundhay and Weetwood, which the earlier investigations showed to possess the least smoke infested atmosphere. It is doubtful if they would ever do well in any district where the annual deposit of soot amounts to more than 50 tons per square mile.

Plants whose leaves are possessed of a crinkled hairy surface, thus easily catching the soot, and of a thin cuticle readily damaged by the acid rain, are also particularly sensitive to smoke pollution. On the other hand, those possessing a hard smooth leathery type of leaf with thick epidermis, like many of the alpines, pinks, carnations, auriculas, London pride and iris, are particularly resistant. Thus the primrose does badly in Hunslet, makes little or no growth, rarely flowers and never lives through more than one winter ; while the auricula is as hardy as possible, and not only lives but thrives, grows and spreads. One border five yards long, which last spring was a mass of bloom, is the result of five years' propagation from four small plants. The geranium can be grown in a smoke infested area, but the calceolaria is always a failure.

Perhaps no plant of this type gives a better index of the amount of smoke pollution than the hollyhock. Six years ago eight hollyhocks (all propagated from the same parent plant) were planted in tubs containing soil taken from the same field of the Experimental Farm of the University of Leeds and the Yorkshire Council for Agricultural Education. The tubs were then placed, two at each station, in four different parts of Leeds. At only one station, that furthest north, did they flower the first year. In the second year more than eight feet of growth was made at Adel, three miles to the north, while in the industrial area of Hunslet one plant only survived, a wizened flowerless specimen, nine inches high.

Plants which have to "lay up a store for another year" tell their own tale of smoke pollution. Heavily handicapped in their growth by the effects of these atmospheric impurities, they have little chance of laying up reserves. This is noticed both in the case of the bulbous and seed-bearing plants. Radishes will grow in Hunslet, but they will run to leaf and will not form bulbs. Tulips, narcissi, daffodils, scillas and hyacinths can be grown there and they will flower one year, but if a second year's bloom is desired, the bulbs must be replaced. Wheat, oats and barley can be grown in Hunslet and you will get plants, but the grain, as can be seen from Plate XIV, Figs. 1 and 2, will not be worth the harvesting.

You may grow lettuces and cabbages in Hunslet, but you must not expect them to heart.

A casual glance at the hedgerows will give some guide as to the extent of smoke pollution in any particular area, for the hawthorn is one of the smoke-sensitive plants and one of the first to go under.

Notice the flora of the lawns and fields of any particular district. In a smoke infested area, the leguminous plants, the clovers and vetches, will be conspicuous mainly by their absence. The finer grasses, particularly the fescues, will be missing. Coarse growing grasses like bent, couch and Yorkshire fog will be in the ascendant, and acid-loving plants like dock, sorrel and plantain will abound. If a lawn is required in the industrial area of Leeds it must be sown down each year.

In the Hunslet parish churchyard, surrounded on all sides by huge chimneys belching out smoke, even bent and the hardy

poa annua have been killed, and the only sign of vegetation is to be found in a few blades of twitch still struggling for existence. The garden of a large residential house left stranded close to the church is a pitiable sight. Its only flower is the iris, which still blooms freely, its only shrub or tree is the elder ; its only fruit or vegetable is the rhubarb ; and its only grass is twitch.

Though apparently the elder will grow anywhere, no matter how great the pollution from coal smoke, it can still give some indication as to the amount of that pollution. Though it will grow in the industrial area of Hunslet, it will not flower. Though it will flower in the residential area of Headingley, two miles from the centre of Leeds, it will not fruit. Apparently it will not flower in localities where the annual deposit of soot is greater than 200 tons per square mile, nor will it fruit if the annual deposit is greater than 50 tons per square mile.

Evidently "The General Type of Vegetation" in any particular district will give some information as to the amount of pollution by coal smoke within the area.

2. The *General Appearance of Individual Plants* is also worthy of attention.

No one coming into Leeds by the Great Northern Railway and looking out of the carriage window near Ardsley station could doubt the fact that he was entering a smoke infested area ; for here almost every tree and every hedge has been killed. In the woods of Middleton and Templenewsam the trees are to a great extent an index of the smoke pollution from colliery, coke oven and brickworks. Here many of the trees, particularly the ash, oak, elm and beech have been absolutely killed, most of them dying from the top. The main drift of the smoke from the industrial area of Hunslet can be easily traced almost to Garforth by the line of dead and dying trees.

Signs of smoke damage to trees can be discerned quite early in the year, in the appearance of the young shoots and buds, many of which are killed off before opening.

The leaf perhaps is the safest index. Before May is out, many leaves in smoky districts are showing characteristic brown blotches. In the case of leaves possessing a thin epidermis like the lime and sycamore, the signs of smoke

damage are seen all over the leaf, wherever the acid rain drops. (Plate III, Figs. 4 and 5.)

In the case of the ribes, the leaves of which possess a harder cuticle and have a tendency to offer a convex surface, the damage is shown by a red rim all round the edge (Plate III, Fig. 3). In the case of leaves like those of the laurel and aucuba, which possess a hard cuticle and have a tendency to hang downwards, the damage is shown first at the tip of the leaf. Reference has already been made to the fact that evidence as to the amount of smoke pollution can also be obtained by the appearance of trees in the autumn ; the greater the pollution the earlier the " leaf fall." Ash trees in the purer parts of Leeds often retain their leaves six or eight weeks longer than those in the more contaminated districts. Thus in Hunslet, with an annual solid deposit of 539 tons per square mile, all the ash trees which remained alive had shed their leaves before the 18th of September, 1911, while at Roundhay, with an annual solid deposit of 26 tons per square mile and no measurable acid deposit, practically all were in full leaf up to the beginning of November. Photographic illustrations of these will be found on Plate V.

Evidence of smoke pollution is available at any time in the stunted growth of trees and shrubs, particularly of evergreens. The following particulars with reference to the maximum growth of aucubas in different parts of Leeds are striking. Differences of the same order have been found in the case of the rhododendron and laurel.

District.	Position.	Annual Deposit in tons per square mile.		Maximum height of Aucuba found in district.
		Total Solid Deposit.	Sulphur Compounds expressed as SO_3.	
				ft. in.
Weetwood Lane .	3 miles north	42	28	10 6
Headingley . .	2 miles north	78	33	7 2
University . .	1 mile north	114	38	5 8
Park Square . .	Centre of city	243	56	3 2
Hunslet . . .	Industrial area	539	96	2 0

Even the colour of the flowers in the gardens and woods will give some indication of the amount of smoke pollution. As a general rule the greater the pollution the paler the tint, and the more blues and reds will tend to run to white, and the bronzes to yellow. Intensely coloured flowers will show patches, the scarlet of the geranium in a smoke infested district will be streaked with purple running to blue, and even to white. The blood-red wallflower will be broadly streaked with yellow and in a year or two most of the red will have disappeared.

Certainly the colour of the leaves will be more than suggestive, and signs of smoke pollution are to be found in the black deposit of soot and tar upon the leaf, and the absence of autumn tints.

3. Though, as has been seen, the *General Type of Vegetation* in a district and the *General Appearance of Individual Plants* will give much information as to the amount of smoke pollution in that district, most can be learnt by the *Detailed Analysis* of the plant. We may notice in a general way that the leaves of plants grown in the town are dirty. This can be readily seen from the photographs on Plate III of the holly and aucuba leaves grown in industrial Leeds. We can, however, get a better idea of their relative cleanliness or otherwise, by actually estimating the amount of solid deposit upon a unit area of these leaves. This has been done in the case of a large variety of leaves, and the deposit thus found can easily be correlated with the known amount of smoke pollution in the district in which they have been grown.

The figures given are those found in the case of laurel leaves grown in the districts indicated.

District.	Annual Deposit of Soot in tons per square mile.	Deposit on Leaf expressed in mgms. per square metre of leaf.
Sutton	In the country free from smoke pollution	0
Weetwood Lane . . .	42	158
University	114	718
Hunslet	539	1620

A microscopic examination of the leaf will reveal the fact

that when the plants have been grown in the smoke polluted atmosphere more or less of the stomatal openings will be choked with a tarry deposit. This will be particularly noticeable in the case of evergreens, and most especially in the case of the conifers. The leaves from a juniper grown at Garforth, six miles from Leeds, but well in the drift of the smoke from Hunslet, were examined by Mr. Hector, Lecturer in Agricultural Botany, and he reported that 75 per cent. of the stomatal openings were more or less choked in this way.

We may notice in a general way that flowers grown in a smoke polluted atmosphere lose their brightness of tint; but it is possible by means of the tintometer to get an accurate measure of their colour. We are indebted to Mr. Frank, of the Dyeing Department of the University of Leeds, for the trouble he has taken in analysing by means of Lovibond's tintometer the colours of a large number of flowers. These flowers have been grown in each case from plants propagated at the Stapleton Gardens, Pontefract, from the same parent plant, by Mr. Dobson, an old student of the Agricultural Department of the Leeds University, whose assistance in this and many other respects has been invaluable. Three sets of readings are given.

The first one shows the tendency of all bronze flowers in a smoke infested district to run to yellow; the second shows the cutting down of the red and blue tints; and the third illustrates the fact that the longer a plant remains in a smoky atmosphere the more it loses the power of producing colour; evidently it is not simply a case of mere bleaching but a radical change in the constitution of the plant.

Blood-red Wallflowers, June 13th, 1914.

District.	Annual Deposit.	Direct Tintometer Readings.			
		Red.	Blue.	Yellow.	Total Colour Units.
Weetwood Lane . .	42	36·5	7·0	4	47·5
University . . .	114	22·5	2·5	9	34·0
Hunslet	539	13·0	1·1	9	23·1

Pyrethum, June 28th, 1914.

District.	Annual Deposit.	Direct Tintometer Readings.			
		Red.	Blue.	Yellow.	Total Colour Units.
Weetwood Lane . .	42	38·6	3·8	0	42·4
University	114	30·0	2·8	0	32·8
Hunslet	539	26·0	1·5	0	27·5

Lupins, June 18th, 1918.

District.	Growth.	Direct Tintometer Readings.			
		Red.	Blue.	Yellow.	Total Colour Readings.
Hunslet	1 year	10·0	10·2	0	20·2
Hunslet	2 years	7·6	5·0	0	12·6
Hunslet	3 years	4·4	3·2	0	7·6

We may notice casually the fact that smoke pollution means stunted growth, but we may get a measure both in the laboratory and *in situ* of the growth of plants, where the conditions other than atmospheric conditions are the same; and the relative growth will be found to be roughly inversely proportional to the smoke pollution. In the laboratory the relative growth has been measured by estimating the amount of carbon dioxide assimilated by a unit area of leaf in a unit of time. The following results refer to experiments—described in detail on page 26—made with laurel leaves of the current year's growth taken from shrubs grown in the districts mentioned.

	Annual Deposit in tons per square mile.	Relative assimilation of CO_2 per unit area of leaf in unit of time.
Weetwood Lane . . .	42	100
Headingley	78	53
Clarendon Road . . .	200	15
Park Square	243	12

In situ the relative growth of plants in different districts has been compared, by filling large wooden buckets with soil taken from the same field in the country, sinking the buckets in gardens in different parts of the town, where the amount of smoke pollution has previously been determined; using the soil for growing a succession of crops each successive year and carefully weighing the produce. In selecting the various stations care was taken that the altitude, exposure and all conditions other than atmospheric smoke pollution should be as nearly as possible identical. Apart from a few slight irregularities the results indicate a fairly close correlation between the relative degree of purity of the atmosphere in the neighbourhood of the station, as determined from earlier observations, and the actual amount of plant growth obtainable.

Station.	Relative purity of air as measured by freedom from Sulphur.	Relative Weight of Crop.			
		1st Crop, Radishes, 1911.	2nd Crop, Lettuce, 1912.	3rd Crop, Cabbage, 1913.	4th Crop, Wallflower 1914.
Weetwood . . .	100	100	100	100	100
Headingley . . .	70	90	86	122	32
University . . .	55	60	74	89	6
Park Square . .	37	49	40	37	2
Hunslet	34	46	31	15	3

An examination of the roots of plants will give some indication of the amount of smoke pollution; plants grown in soil that has been for long exposed to such pollution being marked by an almost entire absence of root hairs and fibrous hairs. The differences in the root development of the wallflowers grown in soil which has been exposed to various districts four years were most marked (Plate VI, Fig. 1). Oats and barley were the following year grown in the same districts in the native soils and the differences in root development were still more marked.

The examination of a felled tree, as can be seen from Plate XIII, Fig. 1, will often give valuable information as to the purity of the atmosphere in which it was grown. A chemical analysis

of the plant will give exceedingly useful information as to the amount of smoke pollution in the district in which it was grown. In this connection the analyses given on page 29, of the deposits on aucuba leaves carried out by the Air Analysis Committee of the Field Naturalists' Society of Manchester in the winter of 1890–91, are of interest.

It will be seen that the central localities show the largest deposits of soot and acid ; the sulphuric acid there forming from 6 to 9 per cent., and the hydrochloric acid from 5 to 7 per cent. of the total deposit. But these impurities due to smoke pollution get not only on the leaf but in it. It has already been seen that the stomata of leaves may be choked by a tarry deposit. The leaf may also absorb sulphur dioxide from the atmosphere partly through its stomata and partly in the case of some leaves possess a thin cuticle directly through the epidermis. Hence the sulphur content of leaves will give, perhaps, one of the best indications of the amount of smoke pollution.

A very large number of leaves from different districts have been analysed in this way, the figures quoted are those connected with the laurel leaves referred to on p. 27 which were collected on February 15th, 1913.

District.	Annual Deposit of Soot in tons per square mile.	Percentage SO_3 in dry matter of Leaf.
Sutton	Free from smoke pollution	0·31
Weetwood Lane . . .	42	0·66
University	114	1·28
Hunslet	539	1·98

If this method is used for a comparison of the relative freedom from pollution of different districts, two or three points must be borne in mind. The leaves must be taken from the same variety of trees or shrubs, for different types of leaves will absorb sulphur dioxide at different rates and hence possess different proportions of SO_3. They must also be collected at the same time, for the sulphur dioxide of leaves will increase with age. The total sulphur content expressed as SO_3 of syca-

more leaves grown in Meanwood and analysed by Steuart was 0·48 per cent. in May and 0·75 in August.

The sulphur present in the plant will be partly protein and partly non-protein; and leaves grown in a smoke infested area will not only contain a large amount of sulphur but that sulphur will be present principally in non-protein forms, mainly sulphates. The following analyses of elder leaves collected in June, 1913, at the stations mentioned illustrate this point.

Station.	Yearly Deposit of SO_3 in tons per square mile.	Percentage of SO_3 in dry matter.			Ratio.	
		Protein.	Non-Protein.	Total.	Protein.	Non-Protein.
Sutton . . .	about 8	0·21	0·07	0·28	300	100
Weetwood Lane	28	0·20	0·13	0·33	154	100
Woodhouse Moor	38	0·19	0·18	0·37	105	100
Hunslet . . .	96	0·11	0·48	0·59	23	100

In the autumn of 1919 the Department of Agriculture of the University of Leeds was asked to investigate a bad case of smoke damage to a growing crop of four acres of potatoes. An estimate of the cost of growing and harvesting the crop, drawn up from the details of cultivation supplied by the owner, was £98 18*s.* 0*d.* In return for this outlay of nearly £100, two tons of marketable ware were lifted and sold for £18 18*s.* 0*d.*, and approximately a ton and a half of small potatoes were fed to the pigs. This would mean that the actual loss in out-of-pocket expenses incurred by the grower could not possibly be less than £70 and most probably would be nearer £80. The haulms of potatoes all showed marked signs of smoke damage, even to the eye. A chemical examination of these showed them to possess an abnormally high sulphur content, and a very low ratio of protein to non-protein sulphur. The total percentage of SO_3 present in the dry matter of the leaves was as high as 0·72 per cent., of which only 0·21 per cent. represented protein sulphur, and 0·51 per cent. represented non-protein sulphur.

A chemical analysis of plants grown in smoke infested areas

will also show that they contain proportions of arsenic increasing with the amount of smoke pollution.

A bacteriological examination of soils in smoke polluted districts will also in many cases supply information which will be of service in determining the amount of that pollution. The acidity of the smoke will deplete the soil of its calcium carbonate and in so doing will modify to a large extent the number and activity of the soil flora. The greater the acidity of the soil the smaller the number of bacteria present in the soil, and the less their activity ; the nitrifying organisms being found to be the most susceptible.

District.	Annual Deposit in tons of SO_3 per sq. mile.	Calcium carbonate in soil.	Total No. of bacteria per gram of dry soil.	Nitrifying organisms.	Putrefactive organisms.	Nitrogen fixing organisms.
				Ammonia converted into nitrates.	Ammonia produced from peptone.	Nitrogen fixed per gram of mannite.
		Per cent.	Thousands	Mgms.	Mgms.	Mgms.
Weetwood Lane	28	0·30	1,536	8·7	105	26
Headingley .	33	0·26	1,236	6·4	88	21
University . .	38	0·19	1,054	4·3	78	19
Park Square .	56	0·17	876	1·9	67	18
Hunslet . .	96	0·12	798	1·2	64	15

The above Table gives the results of bacteriological examination of the soil taken from Garforth and exposed for three years in the districts mentioned.

These results indicate clearly that the detrimental effect of the smoky atmosphere upon plant growth is partly due to unfavourable changes in soil—such as the steady depletion of the stock of calcium carbonate, and the inhibition of the activities of the nitrogen-adapting soil flora.

We may notice that plants grown in a smoke polluted atmosphere lose their vitality ; but it is possible in a large number of ways to get a measure of that loss of vitality and to use the information thus obtained to gauge the amount of smoke pollution in different districts.

This loss of vitality will be shown in a diminution of the reproductive powers of the plant, whether propagated from seed or from cuttings.

(*a*) The following table gives the germination capacity of oats grown in 1913 at the stations indicated.

Station.	Annual Deposit in tons per square mile.	Germination Capacity (10 days).
		Per cent.
Adel	29	98
Headingley	78	92
University	114	64
Hunslet	539	17

(*b*) 100 viola cuttings taken from plants grown in Roundhay (annual deposit 26 tons per square mile) were struck in Hunslet and 98 per cent. grew.

100 viola cuttings taken from plants *grown* in Hunslet were struck in Hunslet but not a single cutting grew.

It is shown in the *smallness* and *lack of weight of seeds of plants* grown in a smoke infested area.

Weight of 100 *Corns of Barley grown from Same Seed.*

Where Grown.	Annual Deposit in tons per square mile.	Weight of 100 corns.
		Gms.
Easingwold	Free from smoke pollution	4·85
Adel	29	4·81
Headingley	78	4·35
University	114	2·27
Hunslet	539	1·16

It is shown not only in the diminution of the germination capacity, but also in the diminution of the *Germination Energy.*

It is shown in the inability of the plant to put up a fight against adverse conditions, as, for example, the winter frosts. To test this point nine cabbage plants were planted out in the autumn of 1913 at the five stations mentioned.

Station.	Annual Deposit in tons per square mile.	Observations.
Weetwood Lane	42	8 out of 9 survived the winter.
Headingley . .	78	2 out of 9 survived the winter.
University . .	114	6 dead by Christmas. Frost in February killed the rest.
Park Square .	243	All dead by middle of November.
Hunslet . .	539	All dead before end of October.

Where the total annual smoke deposit exceeds 100 tons per square mile, it is dangerous to adopt autumn planting either of wallflowers, cabbages or spinach. Where that deposit exceeds 200 tons per square mile it is absolutely fatal. More than 100 wallflowers were planted out in Hunslet in September and not one stood the winter. They can be grown in smoke polluted districts but they must be planted out in the spring.

The loss of vitality is shown perhaps more noticeably in the inhibition of the activity of the various *enzymes* or ferments which assist in the chemical processes taking place in the plant. The figures given in the following table refer to laurel leaves collected in February, 1913, and illustrate the way in which the activity of the various enzymes is influenced by smoke pollution.

District.	Annual Deposit in Tons per sq. mile.	Oxidase Activity.	Catalase Activity.	Emulsin Activity.
Sutton . . .	Free from smoke pollution	100	100	100
Weetwood Lane	42	64	47	85
University . .	114	24	37	51
Hunslet . . .	539	0	34	35

The relative lipase activity in the oat grain grown in 1915 in the districts mentioned was measured by allowing the enzymes present in the grain to hydrolize an ethereal salt like ethyl butyrate or ethyl acetate and observing the amounts of acid liberated by titration against N/10 NaOH. The results

show that the activity of this enzyme as well as that of the others previously mentioned is inhibited by smoke pollution.

Effects of Smoke Pollution on Activity of Lipase of Oat Grain.

District.	Relative activity of lipase.
Adel	100
Weetwood Lane	75
Headingley	66
University	54
Hunslet	42

APPENDIX A

The Influence of Coal-smoke upon Health

By Dr. Ascher, District Medical Officer for Hamm, Westphalia.

On account of the low death-rate from tuberculosis amongst coal-miners, it was believed that coal-dust, smoke, and soot were beneficial to health. The following, Table I, shows that this view is incorrect :—

Fifty-fifth Annual Report of the Registrar-General of the United Kingdom.

Table I.

	Death rate per 10,000.	
	T.	N.T.
Labourers in agricultural districts . . .	18·8	18·6
Coal-miners	14·0	32·6
Chimney sweeps and soot merchants . . .	37·1	43·1
Coal heavers	29·7	65·6

T = death rate from tuberculosis.
NT = death rate from lung diseases which are non-tubercular.

Whilst the death-rate from tuberculosis is only small amongst coal-miners, it is not so among others working in coal-dust, smoke and soot. The reason is that coal-miners are a hardy race, living in good social conditions. More important is the fact that the death-rate from non-tubercular lung diseases is higher than among workmen living in the country. The same is the case in Germany.

TABLE II.

	T.	N.T.
Workmen in Prussia, 15–60 years . . .	28·8	16·5
Coal-miners in the Ruhr district	13·1	39·2

Here again the low death-rate from tuberculosis among the coal-miners is due to the fact that they are very robust and earn high wages. The high death-rate from non-tubercular lung disease is again very striking. According to Russell the following number of persons per 100,000 died in and near Glasgow in 1880 :—

TABLE III.

	Contagious diseases.	Lung diseases.	Other diseases.	Total.
Rural districts	289	354	996	1639
City of Glasgow	773	1024	1232	3029
Thinly populated part of Glasgow, 36 persons per acre . .	450	600	870	1920
Densely populated part of Glasgow, 512 persons per acre .	1020	1860	1600	4480

The death-rate in different parts of Manchester per 100,000 for the year ending the third quarter of 1891 was as follows :—

TABLE IV.

	Contagious diseases.	Lung diseases.	Other diseases.	Total.
Thinly populated part . . .	241	534	954	1729
Thickly „ „ (Ancoats)	510	1544	1798	3752

The death rate per 100,000 for the year ending the fourth quarter of 1892 was :—

	Contagious diseases.	Lung diseases.	Other diseases.	Total.
Thinly populated part . . .	175	429	904	1508
Thickly „ „ (Ancoats)	455	1166	1630	3251

" In the above (Tables III. and IV.) phthisis is included among the 'lung diseases'; otherwise the difference would have been much greater."

The higher death-rate from lung diseases in the more densely inhabited parts of the town cannot, therefore, be ascribed to more frequent contagion.

Still more marked is the contrast between acute lung diseases and contagious diseases among those who are most subject to them, namely, children under 1 year.

TABLE V.

1876–1901.

Death-rate per 1,000 under one year.

	NT.	Scarlet fever, measles, German measles, diphtheria and croup.
In six rural districts of Prussia . . .	4·3	29·8
In six industrial districts of Rhineland.	12·6	5·2

Table V. proves that the higher death-rate from non-tubercular lung diseases in the Rhenish districts is not due to worse economical conditions or a more unfavourable climate; for the six districts of East Prussia (Fischausen, Königsberg, Labiau, Goldap, Lyck, and Oletzko) have a considerably poorer population than the six industrial districts of Rhineland (Mühlheim, Ruhr, Essen, Düsseldorf, Crefeld, Aachen, and Saarbrücken). The former have also a longer and harder winter, and a climate subject to great variations of temperature, whilst the six Rhenish districts have a mild and even temperature. Again, in the administrative area of Arnsberg, in Prussia, where there are large industrial centres, the following comparison has been made:—

TABLE VI.

1898–1907. *Death rate per* 10,000.

Non-industrial area.			Industrial area.		
	NT.	T.		NT.	T.
Amsberg . .	28·19	23·59	Dortmond .	36·88	14·99
Meschede . .	26·99	27·35	Bochum . .	35·89	13·78
Brilon . . .	24·50	29·36	Gelsenkirchen	37·35	15·20

The three industrial districts are wealthier, and therefore have a lower death-rate from tuberculosis, but they also have a smokier atmosphere, and therefore a higher death-rate from non-tubercular lung diseases.

Finally, we will compare two equally large towns which are situated at no great distance from one another in the industrial district of Westphalia, which are built in the same style, and differ only in the amount of coal-smoke in the air, namely, Hamm and Gelsenkirchen. Hamm, being situated on the east fringe, receives coal-smoke only from the west; Gelsenkirchen, being in the centre, has an atmosphere constantly charged with smoke.

TABLE VII.

1900–1902. *Death-rate per* 10,000.

Classified according to age.	Hamm (east border). 32,435 pop. 30·6 NT.	Gelsenkirchen (centre). 37,834 pop. 57·4 NT.
0–1 years	228·9	258·9
1–5 „	57·1	131·1
5–10 „	6·5	17·3
10–15 „	1·8	2·6
15–60 „	10·7	34·7
60 and over	140·4	210·2

We see from this table that coal-smoke increases the death-rate from acute non-tubercular lung diseases in all stages of life. This is also the reason why the death-rate from such diseases is higher in Rhenish Westphalia and in Upper Silesia, as seen from the following Table VIII:—

TABLE VIII.

1905–1909.

	Death-rate per 10,000.
Death-rate from acute lung diseases in all German towns with 15,000 population or more	24·0
In equally large towns of Rhenish Westphalian industrial area	34·0
In the industrial districts of Upper Silesia	36·0

A similar result is found in England if the urban and rural districts are compared.

TABLE IX.

Urban Registration Counties.	Death-rate per 10,000.		Rural Registration Counties.	Death-rate per 10,000.	
Glamorgan	27	1903–04	Buckingham	16	1902–04
Lancaster	29	1902–04	Cambridge	19	,,
London	24	,,	Cornwall	20	,,
Middlesex	19	,,	Hereford	18	,,
Monmouth	27	,,	Huntingdon	16	,,
Northumberland	25	,,	Lincoln	19	,,
Nottingham	27	,,	North Wales	—	,,
Stafford	25	,,	Norfolk	19	,,
Warwick	23	,,	Oxford	17	,,
East Riding	24	,,	Rutland	22	,,
West Riding	20	,,	Somersetshire	17	,,
			Westmorland	11	,,
Average	26·5		Suffolk	16	,,
			Wilts	17	,,
				17·5	

Taking the results of Tables I to IX, there can be little doubt that coal-dust, smoke, and soot increase the death-rate from acute lung diseases.

APPENDIX B

Analyses and Manurial Value of Soot

The dried sample of soot was first extracted with ether in a Soxhlet extractor, the ether soluble material being looked upon as tar.

Carbon and hydrogen were then estimated in the ether insoluble residue by the ordinary combustion method, taking the precautions necessary for substances containing nitrogen, halogens,[1] and sulphur.

The incombustible matter left over from this operation was regarded as ash.

Nitrogen was determined in the dry sample by the Kjeldahl-Gunning method.

In the estimation of sulphur, the original dry soot was fused in a platinum crucible, over asbestos, with its own weight of pure calcined magnesia, and half its weight of dry sodium carbonate. When the organic matter was completely burnt, the residue was taken up with distilled water and hydrochloric acid, oxidized with bromine water, and the sulphates, thus formed, precipitated from the boiling solution with barium chloride in the ordinary way.

The acidity was determined by shaking with distilled water for half an hour in a shaking machine, filtering under pressure, and titrating the clear filtrate against standard alkali, using congo red as indicator.

Chlorine was estimated by extracting with water, as in the case of "acidity," exactly neutralizing with caustic soda, and titrating against standard silver nitrate.

[1] See Cohen, *Practical Organic Chemistry*, pp. 10 and 11.

Analyses of Domestic Soot from Winston Gardens.

	Original coal.	Kitchen soot.	Dining-room.						
			0–5 ft.	5–10 ft.	10–15 ft.	15–20 ft.	20–25 ft.	25–30 ft.	30–35 ft.
Carbon . . .	76·80	52·34	36·45	35·13	38·58	34·14	34·60	36·27	37·2
Hydrogen . .	4·90	3·68	3·51	3·48	3·59	3·47	3·72	3·57	3·5
Nitrogen . . .	1·72	4·11	6·89	7·07	5·48	6·04	6·02	5·46	5·05
Ash	1·80	17·80	5·09	5·52	4·16	4·97	4·45	4·36	4·94
Tar(Ether extract)	0·88	12·46	34·87	38·11	34·91	37·2	38·17	40·94	40·38
Sulphur . . .	0·79	2·20	2·18	3·07	2·48	2·56	2·64	3·22	2·45
Chlorine . . .	0·25	1·35	9·07	7·37	8·43	6·41	5·53	5·07	4·96
Acidity . . .	0·0	0·28	0·92	0·92	0·65	0·55	0·70	0·68	0·92
Arsenic (see p. 64)									

Manurial Value of Soot.

Apparent density	0·2748	0·2048	0·1922	0·1964	0·2450	0·2313	0·2428	0·2865
No. of lbs per bushel . . .	22	16½	15½	15½	19½	18½	19½	23
Value per bushel	5½*d.*	6½*d.*	6½*d.*	5½*d.*	7*d.*	6½*d.*	6½*d.*	7*d.*
Value per ton .	£2 3 0	£3 17 0	£3 19 0	£3 16 0	£3 7 6	£3 7 6	£3 1 0	£2 16 0

Analyses of Domestic Soot from North Grange Mount, Headingley.

	Original coal.	Kitchen flue.	Study flue.
Carbon	76·47	45·91	47·15
Hydrogen	5·22	2·18	4·85
Nitrogen	1·32	2·33	5·57
Ash	2·10	27·34	20·22
Tar	0·92	10·20	15·68
Sulphur	0·99	1·46	2·32
Chlorine	0·27	4·64	6·46
Acidity	0·0	0·0	0·50
Arsenic (see p. 65)			

Manurial Value of Soot.

Apparent density . . .		0·3265	0·2368
No. of lbs. per bushel . .		25½	19
Value per bushel . . .		3½*d.*	6¼*d.*
Value per ton		£1 4 5	£3 2 5

Analyses of Soot from University.

	Original coal.	Domestic soot.	Boiler soot.			
			Base.	13 ft. up.	70 ft. up.	Top.
Carbon	69·30	40·50	19·24	16·66	21·80	27·00
Hydrogen	4·89	4·37	2·71	0·86	1·44	1·68
Nitrogen	1·39	4·09	0·23	0·00	1·18	1·09
Ash	8·48	18·16	73·37	75·04	66·04	61·80
Tar	1·64	25·91	0·09	0·28	0·80	1·14
Sulphur	1·74	2·99	2·76	2·07	2·58	2·84
Chlorine	0·27	5·19	0·11	0·75	1·46	1·60
Acidity	0·0	0·39	1·62	1·04	0·58	0·47
Arsenic (see p. 64)						
Manurial Value of Soot.						
Apparent density		0·340	0·447	0·467	0·436	0·429
No. of lbs. per bushel		27·0	35·8	37·4	34·9	34·3
Value per bushel		8½*d.*	½*d.*	0*d.*	2½*d.*	2½*d.*
Value per ton		£2 6 0	2*s.* 6*d.*	nil	13*s.* 2*d.*	12*s.* 2*d.*

Analyses of Soot from Brass Foundry in Leeds. Liquid fuel used.

	Base.	Top.
Carbon	11·36	47·71
Hydrogen	1·03	2·35
Nitrogen	0·11	2·32
Ash	82·16	31·42
Tar	1·02	10·62
Sulphur	2·23	4·36
Chlorine	0·28	1·47
Acidity	0·00	0·65
Manurial Value of Soot.		
Apparent density	0·7915	0·5017
No. of lbs. per bushel	63·3	40·1
Value per bushel	½*d.*	5½*d.*
Value per ton	1*s.* 3*d.*	£1 5 11

Attention has been called on p. 4 to the great outstanding differences in the composition of domestic and boiler soots, these differences being due principally to differences both in temperature and in draught. Thus, a boiler soot is characterized by the high percentage of mineral matter it contains, and by the smallness of its content of combustible matter, *i.e.* carbon and hydrogen, and volatile products, *i.e* tar, ammonium chloride, and ammonium sulphate. Domestic soots, on the other hand, are rich in volatile and combustible matter, and poor in ash or mineral matter. It is interesting, too, to note in the case of boiler soots, that further up the chimney where the temperature is naturally lower we get a striking increase in the percentage of carbon, tar, and ammonium chloride, and a corresponding decrease in the percentage of ash. In the case of domestic soots, however, the differences in composition as we get further from the source of combustion are not so striking and not always in the same direction as those observed in the case of boiler soots. Thus, while there is a slight tendency for the percentage of tar to increase and the percentage of ash to decrease, the amount of an easily condensible volatile product like ammonium chloride apparently reaches its maximum about ten feet from the base of the chimney, and then steadily decreases.[1]

As a manure, soot is valuable principally on account of the nitrogen it contains, this nitrogen being present almost entirely in the form of ammonium chloride or ammonium sulphate. As nitrogen in this form is worth commercially about 12*s.* a unit of 6*d.* a pound, and as the nitrogen content of soot may vary from 0 to 7 per cent., it naturally follows that the commercial value of soot as a fertilizer will vary from nothing to £4 per ton. As most soot is disposed of locally at from £2 10*s.* to £3 per ton and as no guarantees can be obtained as to its composition, the purchaser may or may not be getting value for his money. Fortunately, however, some indication of the value of soot as a fertilizer can be obtained from its density, and the lighter the soot the higher as a rule will be its nitrogen content and the greater its commercial value. A bushel of domestic soot will, as a rule contain 1 lb. of nitrogen, and approximate in value to about 6*d.*; it is, therefore, advisable to buy by the bushel rather than by the ton. Further, no genuine domestic soot should weigh more than 1 quarter to the bushel, and any sample weighing more than 28 lbs. to the bushel may be looked upon as being a boiler soot possessing little or no fertilizing value.

[1] Cohen and Ruston, *J. Soc. Chem. Ind.*, 1911.

APPENDIX C

Analyses of Leeds Rain-water [1]

From October, 1906, to the end of 1909 samples of rain falling on the Manor Farm, Garforth (Experimental Farm of the University of Leeds and Yorkshire Council for Agricultural Education), were periodically collected and analysed. The farm is situated some six miles due east of the city of Leeds. The prevailing winds are westerly, and hence convey much of the impurity of the Leeds atmosphere over the farm.

The outstanding feature of these Garforth results is the relatively high amount of each of the different impurities estimated.

Thus, for the four years 1906–1909 the total number of pounds of nitrogen deposited per acre [2] at Garforth amounted to 9·8, as compared with 3·8 the average at Rothamsted; the average precipitation of sulphur was equivalent to 96 pounds of SO_3 at Garforth, as compared with 17 pounds at Rothamsted. The average yearly precipitation of chlorine was 21 pounds as compared with the Rothamsted average of 15 pounds, while the impure nature of the Garforth atmosphere is strikingly illustrated by the fact that free acid equivalent to no less than 20 pounds of sulphuric acid is yearly brought down by the rain.

Other points of interest are—

(*a*) The amount of nitrogen brought down in the course of the year is largely determined by the amount of the rain. This is clearly evident in the data given below :—

Year.	Rainfall in inches.	Nitrogen (as ammonia + nitric acid.).
1907	27·1	8·45 lbs. per acre
1908	22·7	7·46 „ „
1909	28·5	9·48 „ „

This is also shown by the fact that while the amount of nitro-

[1] Crowther and Ruston, *J. Agric. Science*, vol. iv.

[2] To convert pounds per acre into tons per square mile, multiply by 2/7.

Total Amount of Deposit in Leeds and Garforth Rain.

Tons per square mile.

Station No.	Insoluble (Soot).				Sulphur compounds.				Chlorine.	Nitrogen.			
	Carbon.	Tar.	Ash.	Total.	Free acid H_2SO_4.	As sulphate.	In other forms.	Total.		As ammonia	As nitrate.	As albuminoid.	Total.
1	189·6	31·4	318·0	539·0	10·0	35·2	12·3	47·5	47·0	3·71	0·00	1·34	5·05
2	241·2	19·7	187·2	448·1	26·7	52·9	8·6	61·5	56·5	4·43	0·00	0·83	5·26
3	87·1	42·6	202·5	332·2	8·5	77·0	19·1	96·1	29·0	4·11	0·14	1·00	5·25
4	99·7	22·3	120·6	242·6	12·9	42·5	13·7	56·2	21·4	4·11	0·08	0·63	4·82
5	100·2	12·3	56·9	169·4	3·1	32·3	11·4	43·7	11·7	3·17	0·31	0·23	3·71
6	98·0	9·7	61·7	169·4	8·3	31·4	13·1	44·5	31·0	2·83	0·28	0·91	4·02
7	63·2	9·1	41·7	114·0	7·5	24·3	14·0	38·3	14·6	2·65	0·23	0·46	3·34
8	52·3	8·0	40·3	100·6	2·3	22·0	20·0	42·0	16·3	2·20	0·05	0·65	2·90
9	19·2	7·4	15·4	42·0	3·1	23·4	4·5	27·9	9·7	2·37	0·31	0·60	3·28
10	7·7	4·0	14·0	25·7	0·0	15·1	5·7	20·8	11·0	1·65	0·20	0·37	2·22
11	—	—	—	—	8·0	18·6	7·4	26·0	6·3	1·43	0·91	0·31	2·65

gen actually present in the rain, and expressed in parts per million, is fairly uniform during the summer and winter months, the total amount expressed in pounds per acre is greater during the summer months owing to the heavier rainfall.

(*b*) The winter rain, as at Rothamsted, was decidedly richer in chlorine than that falling during the summer months.

(*c*) The winter rainfall was more than twice as acid as the summer rainfall, the proportion being notably high in the months of December and January.

(*d*) Light rains were proportionately more concentrated than heavy rain.

(*e*) The impurities in the rain are to a large extent influenced by the prevailing winds, rain falling when the wind is blowing from a westerly direction over Leeds being much more impure than that accompanying a north or north-east wind, which would blow over a purely agricultural district, *e.g.*—

		Parts per million			
	Wind.	Total N.	Cl.	SO_3,	Acidity.
October 1–2, 1906 .	W.	0·0917	0·85	1·59	0·465
October 3, 1906 .	N.	0·0419	0·35	1·12	0·350

(*f*) Notwithstanding these variations, the total amount of these impurities brought down yearly, when expressed as pounds per acre, give a fairly constant figure, the largest variation being found in the amount of free acid deposited.

The amounts of chlorine (present as chlorides) found in the yearly rainfall ranged from 27·9 tons per square mile at station 9 to 56·5 tons at station 2. Throughout the semi-industrial and non-industrial area the amount was not more than about 14 tons per square mile, with the exception of station 6, where the total reached 31 tons. This high figure finds an explanation in the salt-glazing process carried on at a neighbouring fireclay works. The excessive amount of this impurity in all the rain-water is largely due to smoke pollution, coal containing roughly 0·3 per cent. of chlorine, and soot sometimes containing as much as 9 per cent. of this substance.[1]

[1] See Appendix B, p. 99.

APPENDIX D

Smoke and the Electrification of Plants

THE recent researches of Professor Priestley and other workers have shown that by means of electrification, plants may be stimulated to give both larger crops and earlier maturity. In Professor Priestley's experiments high tension electricity is discharged from a system of thin insulated wires stretched over the crops. The high tension electrifying at from 50,000 to 100,000 volts was generated by the Lodge Newman system of transformer, valves, etc., and was supplied to a network of thin wires raised some fifteen feet from the ground. Working both in a rural district like Dumfries and in an industrial district like Garforth, near Leeds, his results apparently seemed contradictory; in the former case distinctly beneficial results were obtained, while in the latter district either neutral or negative results were shown. Using the method of electrical discharge under laboratory conditions in Leeds on a small scale, with pot cultures, Professor Priestley found that the unelectrified control plants did much better than the electrified ones, which all seemed to show exaggerated signs of apparent smoke damage, while the benches upon which the electrified pot cultures were standing were thickly coated with a deposit of black smuts.

In his investigations at Garforth, Professor Priestley found great difficulty in obtaining accurate measurements of potential distribution, because of the smoke-laden air. When the wind blew from the direction of some of the collieries south-east of the experimental field, the atmospheric potential varied very considerably, the gradient varying from 50 to 1,000 volts per metre. Steuart and Jorgensen in taking measurements of the potential gradients of the atmosphere from a grass field 150 yards from the Kirkstall Forge in the industrial area of the town, found when the wind was blowing from the Forge that the potential gradient varied rapidly between 720 and 2,200 volts per metre during 40 minutes.

On another occasion, when a slight wind was blowing at right angles to the railway some 300 yards away, and the smoke from the

trains was wafted slowly down to the instruments the passage of each train was timed, and the effect of its smoke upon the potential gradient was seen some five minutes afterwards, when that gradient varied from approximately 120 to 960 volts per metre.

It would appear that the high potential gradient causes a segregation of the smaller smoke particles, the larger coalesced particles being then more quickly deposited and thus accentuating the smoke damage.

In order to test whether this was actually the case, funnels were placed in the " Peat Mires," one of the experimental fields at Garforth, the crops in which were being subjected to high tension electrical discharge, and others were placed in adjoining fields not so treated. The rain water collected in the funnels was analysed at the end of each month, and from the results of the analyses it was quite evident that the electrification of the atmosphere brings about a heavier deposition of soot particles, and that these soot particles act as nuclei of condensation for other smoke products.

	Parts per Million.	
	Electrically Treated.	Untreated.
Suspended matter	270·8	81·0
Tar	15·3	3·8
Acidity as H_2SO_4	10·3	10·6
Sulphur SO_3	33·2	15·6
Sulphur as SO_2	7·2	0·36
Chlorine	24·9	10·3
Nitrogen NH_3	4·12	1·481
Nitrogen as N_2O_5	0·813	0·493
Nitrogen as albuminoid ammonia .	0·434	0·167
Total nitrogen	5·367	2·041

If these results generally hold good they indicate that while the electrification of plants may prove beneficial in the rural districts, the process cannot be used to advantage in the districts where its value might be greatest, such as in the market gardening districts in the neighbourhoods of the industrial areas. In such areas the intensified smoke effects would more than counterbalance the good effects which might otherwise result from the electrical treatment.

INDEX

Acid, in air, 40, 70 ; in leaves, 60 ; in rain, 40–43 ; in soil, 55 ; in soot, 7, 29, 40 ; action on masonry, 45 ; on metal work, 52 ; on vegetation, 53.
Air, amount of acid, 40, 70 ; of ammonia, 62 ; of chlorine, 62 ; of carbon dioxide, 26, 69 ; of sulphur di-oxide, 72 ; of solid impurities, 11
Ammonia, in rain-water, 62 ; in soils, 55
Amount of soot from chimneys in Glasgow, 14, 19 ; in Leeds, 16, 19 ; in London, 14, 19 ; in Manchester, 14 ; in United Kingdom, 11
Analyses of air, 11, 12, 26, 40 ; of rain-water, 102 ; of soot, 5, 73, 98
Apparatus for assimilation experiment, 26 ; for estimating solid impurities in air, 12 ; sulphur dioxide in air, 70 ; for washing air, 45
Arsenic in coal, dust, rain and soot, 63
Ascher, Dr., influence of coal-smoke on health, 93
Ash trees, effects of smoke, 29, 82
Assimilation of carbon dioxide by leaves, 25, 85

Bacteria, in acid soils, 34, 56, 89
Baines, Sir F., smoke damage to Public Buildings, 49
Barley, effects of smoke on, 80, 90

Cabbages, effects of smoke, 32, 80, 86
Carbon dioxide, in air, 26 ; in fog, 69
Chlorine in rain-water, in Leeds, 42, 60 ; in London, 40 ; in Rothamsted, 41
Coal, arsenic present, 63 ; composition of, 5 ; consumption in Leeds, 22 ; in United Kingdom, 11
Coal-smoke, influence on health, 93
Colour, influence of smoke upon, 83, 85
Combustion, incomplete, 4
Composition of coal, 5, 99 ; of rain-water, 102 ; of soot, 5, 73, 98

Daily soot-fall, Glasgow, 14, 19 ; Leeds, 14, 19 ; London, 14, 19
Death-rate in town and country, 93
Deposit of soot on leaves, 29, 83
Des Vœux and Owens, experiments on soot, 14
Disintegration of stonework by acid, 45
Dispersal of soot, 77
Dust particles in air, 66

Effects of smoke on ash trees, 29, 82 ; on barley, 80, 90 ; on cabbages, 32, 80, 96 ; on enzymes, 91 ; on fog, 66 ; on germination, 90 ; on grasses, 53 ; on health, 93 ; on lettuces, 31 ; on light, 35 ; on masonry, 45 ; on metal work, 52 ; on mortar, 45 ; on potatoes, 88 ; on radishes, 31 ; on ribes, 82 ; on root development, 86 ; on Scotch firs, 24, 30 ; on wallflowers, 32, 86 ; on soils, 55 ; on vegetation, 23
Electrification of plants, 105

Fir trees, effects of smoke, 24, 30
Fog in towns, 66 ; effect on rain, 74 ; on sulphur di-oxide in air, 72 ; on soot deposit, 74
Fuel lost as soot, 11
Fyfe, P., experiments on soot, Glasgow, 14

Garforth rain, effect of fog, 74 ; of soot, 53 ; on grasses, 53
Gaseous impurities in air, 39, 60
Grasses, effects of acid, 53

Harris, F. W., experiments on soot deposits, 14

Irwin, W., experiments on soot deposits, 14

Jackson, Prof. H., experiments on corrosion of masonry, 46

Leaf-fall, effect of smoke on, 29
Leaves, assimilation of carbon dioxide, 25; deposit on, 29, 91; sulphuric acid on, 60
Leeds air, amount of soot, 12; of dust, 66
Leeds rain, analysis of, 102
Lettuces, effects of smoke, 31
Light intensity, 35
Light tests, 36
Limestone, effects of sulphuric acid, 46

Manurial value of soot, 98
Map of Leeds, 15
Masonry, effects of acid, 45
Metal work, action of acid, 52
Mortality in town and country, 93

Nitrates in soil, 34, 55, 89; in rain, 62
Nitrogen in rain as ammonia, etc., 62, 102; in soils, 34, 55, 89

Owens, Dr. J. S., dust counter, 67

Rain-water, analyses of, 43; arsenic in, 63; at Garforth, 53, 74; at Leeds, 16, 53, 61; at London, 7; at Rothamsted, 41.

Sandstone, effects of sulphuric acid, 47
Smoke effects on ash trees, 29, 82; on barley, 80, 90; on cabbages, 32, 80, 96; on enzymes, 91; on fog, 66; on germination, 90; on grasses, 53; on health, 93; on lettuces, 31; on light, 35; on masonry, 45; on metal work, 52; on mortar, 45; on potatoes, 88; on radishes, 31; on ribes, 82; on root development, 86; on soils, 55; on trees, 24, 30; on vegetation, 23; on wallflowers, 32, 86
Snow, soot in, 73; sulphates in, 42
Soil, analyses of, 34, 55; effects of acid, 34, 55
Solid impurities in air, 11; in rain, 16, 103
Soot, amount emitted, 7; produced in United Kingdom, 11; present in hoar frost, 73; in rain, 16; in snow, 14, 73; analysis of, 5, 73, 98; arsenic present, 63; deposits in Glasgow, 14, 19; in Leeds, 14, 19; in London, 14, 19; daily fall, 13; its dispersal, 77; distribution of, 22; effects on vegetation, 23; manurial value of, 98
Soot tar, its amount, 20; in hoar frost, 73; in rain, 16
Stomata, effects of soot, 24
Sulphates, in rain, 40; in snow, 42
Sulphur acids in air, 39; apparatus for estimation, 44
Sulphuric acid, in leaves, 59; ratio of protein to non-protein, 88; in rain, 42; in soil, 55; in soot, 7; action on masonry, 45; on metal work, 52; on vegetation, 53
Sulphurous acid, in air, 70; in fog, 72

Tar, amount in soot, 5; in hoar frost, 73; in rain, 16
Town fog, 66

Value of soot, 98
Vegetation, effects of soot, 23; of sulphuric acid, 53

Worthington, W. B., experiments on iron rails, 52

Messrs. Edward Arnold & Co.'s Scientific & Technical Publications

PHYSICS

GENERAL ASTRONOMY. By H. Spencer Jones, M.A., B.Sc., H.M. Astronomer at the Cape. viii + 392 pages, with 102 diagrams and 24 plates. Third Impression. Demy 8vo, 21s. net.

THE LIFE OF LORD RAYLEIGH. By his son, Robert John Strutt, Fourth Baron Rayleigh, F.R.S. Demy 8vo, xii +403 pages. 25s. net.

ISOTOPES. By F. W. Aston, Sc.D., D.Sc., F.R.S., Nobel Laureate, Fellow of Trinity College, Cambridge. viii + 184 pages, with diagrams and plates. Second Edition. Demy 8vo, 10s. 6d. net.

IONS, ELECTRONS, AND IONIZING RADIATIONS. By J. A. Crowther, M.A., Sc.D., Professor of Physics at University College, Reading. Fourth Edition. Thoroughly revised. xii+328 pages. Demy 8vo, 12s. 6d. net.

THE DYNAMICAL THEORY OF SOUND. By Horace Lamb, Sc.D., F.R.S., Rayleigh Lecturer in the University of Cambridge. Second Edition. viii + 307 pages. Demy 8vo, 18s. net.

AN INTRODUCTION TO THE THEORY OF OPTICS. By Sir Arthur Schuster, Sc.D., F.R.S., Honorary Professor of Physics in the Victoria University of Manchester. Third Edition. Revised by the Author and J. W. Nicholson, D.Sc., F.R.S., Fellow and Tutor of Balliol College, Oxford. xvi+405 pages, 188 illustrations. Demy 8vo, 18s. net.

COLOUR VISION. A Discussion of the Leading Phenomena and their Physical Laws. By W. Peddie, D.Sc., F.R.S.E., Harris Professor of Physics at University College, Dundee. xii + 208 pages. Illustrated. Demy 8vo, 2s. 6d. net.

AERONAUTICS IN THEORY AND EXPERIMENT. By W. L. Cowley, A.R.C.S., D.I.C., and H. Levy, M.A., B.Sc., F.R.S.E., Assistants at the National Physical Laboratory. With numerous illustrations and diagrams. Second Edition. xii + 332 pages. Demy 8vo, 25s. net.

NAVIGATION NOTES AND EXAMPLES. By Instructor Captain S. F. Card, B.A., R.N., late Head of the Navigation Department and Lecturer in Navigation at the Royal Naval College, Greenwich. Third Edition. xviii + 252 pages. Demy 8vo, 12s. 6d. net.

A TEXT-BOOK OF PHYSICS. By R. S. Willows, M.A. (Camb.), D.Sc. (London), late Head of the Department of Mathematics and Physics at the Sir John Cass Technical Institute; Member of the Council of the Physical Society. Third Edition. viii + 520 pages, with 320 diagrams. Large crown 8vo, 9s. net.

AN INTRODUCTION TO FLUID MOTION. By W. N. Bond, D.Sc., F.Inst.P., Lecturer in Physics at University College, Reading. Crown 8vo, 5s. net.

HEAT. By W. J. R. Calvert, M.A., Harrow School. viii + 344 pages, with 138 diagrams. Crown 8vo, 6s.

ELECTRICITY AND MAGNETISM. By C. E. Ashford, M.A., Headmaster of the Royal Naval College, Dartmouth. With over 200 diagrams. Third Revised Edition. Crown 8vo, 4s. 6d.

MAGNETISM AND ELECTRICITY. By J. Paley Yorke, Head of the Physics and Electrical Engineering Department, L.C.C. School of Marine Engineering, Poplar. Crown 8vo, 5s.

AN INTRODUCTION TO PRACTICAL PHYSICS. By E. H. Barton, D.Sc., F.R.S.E., Professor of Experimental Physics, University College, Nottingham; and the late T. P. Black, M.Sc., Ph.D. 55 Figures. Second Edition. Crown 8vo, 5s.

ADVANCED EXAMPLES IN PHYSICS. By A. O. Allen, M.A., B.Sc., A.R.C.S., Lecturer in Optics at Leeds University. Second Edition. Crown 8vo, 2s. 6d. net.

MATHEMATICS

FIVE-FIGURE TABLES OF MATHEMATICAL FUNCTIONS. By J. B. Dale, M.A., Assistant Professor of Mathematics at King's College, London. Demy 8vo, 4s. 6d. net.

LOGARITHMIC AND TRIGONOMETRIC TABLES (To Five Places of Decimals). By J. B. Dale, M.A. Demy 8vo, 2s. 6d. net.

THE CALCULUS FOR ENGINEERS. By John Perry, M.E., D.Sc., F.R.S. Thirteenth Impression. viii + 382 pages. Crown 8vo, 8s. 6d.

CALCULUS FOR SCHOOLS. By R. C. Fawdry, M.A., Head of the Military and Engineering Side at Clifton College; and C. V. Durell, Senior Mathematical Master at Winchester College. Crown 8vo. With Answers. In one volume, 6s. 6d. Part I, 3s. 6d.; Part II, 4s.

AN INTRODUCTION TO PROJECTIVE GEOMETRY. By L. N. G. Filon, M.A., D.Sc., F.R.S., Professor of Applied Mechanics, University College, University of London. Third Edition. viii + 261 pages. Crown 8vo, 7s. 6d.

MATHEMATICAL DRAWING. Including the Graphic Solution of Equations. By the late G. M. Minchin, M.A., F.R.S.; and J. B. Dale, M.A. Third Edition, Second Impression. vi + 145 pages. Demy 8vo, cloth, 8s. 6d. net.

HIGHER ALGEBRA. By W. P. Milne, M.A., D.Sc., Professor of Mathematics in the University of Leeds. xii + 586 pages. Crown 8vo, 8s. 6d.

HOMOGENEOUS CO-ORDINATES. By W. P. Milne, M.A., D.Sc. xii + 164 pages. Crown 8vo, 6s. net.

EXAMPLES IN THE MATHEMATICAL THEORY OF ELECTRICITY AND MAGNETISM. By J. G. Leathem, M.A., Fellow of St. John's College, Cambridge. Crown 8vo, cloth, 2s.

GEOMETRICAL CONICS. By G. W. Caunt, M.A., and C. M. Jessop, M.A., Armstrong College, Newcastle-on-Tyne. Crown 8vo, 3s.

ENGINEERING

THE STRENGTH OF MATERIALS. A Treatise on the Theory of Stress Calculations for Engineers. By J. Case, M.A., F.R.Ae.S., Lecturer in Applied Mechanics at the Royal Naval Engineering College, Keyham. Med. 8vo. viii + 558 pages. 30s. net.

STRENGTH AND STRUCTURE OF STEEL AND OTHER METALS. By W. E. Dalby, F.R.S., M.A., B.Sc., M.Inst.C.E., M.I.M.E., University Professor of Engineering at the City and Guilds (Engineering) College. Very fully illustrated. 192 pages and 38 plates. 8vo, 18s. net.

STEAM POWER. By Professor W. E. Dalby, F.R.S., M.Inst.C.E., M.I.M.E. Second Edition. xvi + 760 pages, with 250 diagrams. 8vo, 25s. net.

VALVES AND VALVE GEAR MECHANISMS. By Professor W. E. Dalby, F.R.S. xviii + 366 pages, 202 illustrations. Royal 8vo, 24s. net.

THE BALANCING OF ENGINES. By Professor W. E. Dalby, F.R.S. Third Edition. xii + 283 pages, 184 illustrations. Demy 8vo, 12s. 6d. net.

PROPERTIES OF STEAM AND THERMODYNAMIC THEORY OF TURBINES. By H. L. Callendar, F.R.S., Professor of Physics in the Imperial College of Science and Technology. 544 pages, numerous diagrams. 8vo, 30s. net.

THE ENLARGED CALLENDAR STEAM TABLES. (Fahrenheit Units.) 7s. 6d. net.

THE CALLENDAR STEAM TABLES. 3s. 6d. net.

ABRIDGED CALLENDAR STEAM TABLES. (Centigrade Units.) 8vo, 1s. net.

ABRIDGED CALLENDAR STEAM TABLES. (Fahrenheit Units.) 8vo, 1s. net.

THE MOLLIER DIAGRAM. Drawn by Professor Callendar and printed on green squared paper. 1s. net.

THE ENLARGED MOLLIER DIAGRAM. Drawn by Professor Callendar. Printed in three colours on squared paper. 4s. net.

THE CALLENDAR STEAM DIAGRAM. (Centigrade Units.) 6d. net.

THE CALLENDAR STEAM DIAGRAM. (Fahrenheit Units.) 6d. net.

HEAT DROP TABLES: ABSOLUTE PRESSURES. Calculated by H. Moss, M.Sc., A.R.C.S., from the Formulæ and Steam Tables of Professor H. L. Callendar, F.R.S. 64 pages. Cloth, 5s. net.

HEAT DROP TABLES: H.P. GAUGE PRESSURES, L.P. ABSOLUTE PRESSURES. Calculated by H. Moss, Imperial College of Science, from Professor Callendar's Formulæ and Steam Tables. Cloth, 5s. net.

THE ENLARGED HEAT DROP TABLES: H.P. GAUGE PRESSURES, L.P. ABSOLUTE PRESSURES. 10s. 6d. net.

CORRECTION TABLES FOR THERMODYNAMIC EFFICIENCY. Calculated by C. H. Naylor, Assoc.M.Inst.C.E. Cloth, 5s. net.

STEAM TURBINE DESIGN. By John Morrow, M.Sc., D.Eng., Armstrong College, Newcastle-on-Tyne. *[New Edition in Preparation.*

RAILWAY ELECTRIC TRACTION. By F. W. Carter, M.A., M.I.E.E., British Thomson-Houston Co., Rugby. viii + 412 pages, with 204 illustrations and 10 folding plates. Demy 8vo, 25s. net.

THE MEASUREMENT OF FLUID VELOCITY AND PRESSURE. By the late J. R. Pannell. Edited by R. A. Frazer, B.A., B.Sc., National Physical Laboratory. viii + 138 pages. 10s. 6d. net.

HYDRAULICS. For Engineers and Engineering Students. By F. C. Lea, D.Sc., M.Inst.C.E., Professor of Mechanical Engineering in the University of Sheffield. Fourth Edition. xii + 594 pages, 400 diagrams. Demy 8vo, 18s. net.

ELEMENTARY HYDRAULICS. For Technical Students. By F. C. Lea, D.Sc., M.Inst.C.E. viii + 224 pages, with 156 diagrams. Crown 8vo, 7s. 6d. net.

MODERN METHODS OF WATER PURIFICATION. By John Don, F.I.C., A.M.I.Mech.E., and John Chisholm, A.M.I.Mech.E. Second Edition. xviii + 398 pages, 106 illustrations. Demy 8vo, 16s. net.

MODERN ROADS. By H. P. Boulnois, M.Inst.C.E., F.R.San.Inst., etc. xii + 302 pages. Demy 8vo, 16s. net.

REINFORCED CONCRETE DESIGN. Vol. I.: Theory. By Oscar Faber, D.Sc., A.M.Inst.C.E., Chief Engineer to Messrs. Trollope and Colls, Ltd., and P. G. Bowie, A.M.Inst.C.E. xx + 332 pages, 158 diagrams. Second Edition. Demy 8vo, 14s. net. Vol. II.: Practice. By Oscar Faber, D.Sc., A.M.Inst.C.E. xii + 246 pages, 89 diagrams. Demy 8vo, 18s. net.

THE PRACTICE OF RAILWAY SURVEYING AND PERMANENT WAY WORK. By S. Wright Perrott, M.A.I., M.Inst.C.E., Professor of Civil Engineering in the University of Liverpool; and F. E. G. Badger, A.M.Inst.C.E. viii + 304 pages, with 140 diagrams. Demy 8vo, 30s. net.

SURVEYING. By W. N. Thomas, M.Sc. (Birmingham), B.Sc. Eng. (London), Assoc.M.Inst.C.E., A.M.I.Mech.E., A.M.Inst. M. and Cy.E. viii + 536 pages and 298 diagrams. 8vo, 25s. net.

THE FIELD ENGINEER'S HANDBOOK. By G. C. Wells and A. S. Clay, B.Sc. Second Edition. viii + 227 pages, 71 illustrations. Small 8vo, 8s. 6d. net.

TRAVERSE TABLES. With an Introductory Chapter on Co-ordinate Surveying. By Henry Louis, M.A., D.Sc., M.I.C.E., Professor of Mining; and G. W. Caunt, M.A., Lecturer in Mathematics, Armstrong College, Newcastle-on-Tyne. Second Edition. 8vo, 5s. 6d. net.

TACHEOMETER TABLES. By H. Louis, M.A., D.Sc., M.I.C.E.; and G. W. Caunt, M.A. 8vo, 10s. 6d. net.

A TEXT-BOOK OF ELECTRICAL ENGINEERING. By Dr. A. Thomälen. Translated by Professor G. W. O. Howe, D.Sc. Fourth Edition. xii + 482 pages, 480 diagrams. Demy 8vo, 28s. net.

THE PRINCIPLES OF ELECTRICAL ENGINEERING AND THEIR APPLICATION. By Dr. G. Kapp. Volume I.: Principles. xii + 356 pages. Demy 8vo, 18s. net. Volume II.: Application. x + 388 pages. 18s. net.

THE FOUNDATIONS OF ALTERNATE CURRENT THEORY. By C. V. Drysdale, D.Sc. (London), M.I.E.E., F.R.S.E. xii + 300 pages, 190 illustrations. Demy 8vo, 10s. 6d. net.

THE THEORY OF MACHINES. By R. F. McKay, M.Sc., A.M.Inst. C.E., A.M.I.Mech.E. Second Edition. viii + 440 pages, 407 diagrams. Demy 8vo, 20s. net.

THE PRINCIPLES OF MACHINE DESIGN. By R. F. McKay, M.Sc. xii + 408 pages, 284 diagrams. Demy 8vo, 18s. net.

GRINDING MACHINERY. By J. J. Guest, M.A., M.I.Mech.E., Professor of Mechanical and Electrical Engineering, Artillery College, Woolwich. xii + 444 pages, with illustrations. Demy 8vo, 16s. net.

STEAM BOILERS AND BOILER ACCESSORIES. By the late W. Inchley, B.Sc. xi + 412 pages, 141 illustrations. Crown 8vo, 8s. 6d. net.

METAL WORK. By H. M. Adam and J. H. Evans. Second Edition. Crown 8vo.

THE STRENGTH AND ELASTICITY OF STRUCTURAL MEMBERS. By R. J. Woods, M.E., M.Inst.C.E. Second Edition. xii + 310 pages, 292 illustrations. Demy 8vo, 14s. net.

THE THEORY OF STRUCTURES. By R. J. Woods, M.E., M.Inst. C.E. xii + 276 pages, 157 illustrations. Demy 8vo, 12s. 6d. net.

THE ITALIAN ORDERS OF ARCHITECTURE. By Charles Gourlay, B.Sc., A.R.I.B.A., Professor of Architecture and Building in the Royal Technical College, Glasgow. With 32 full-page plates. Large 4to (12″ × 9½″). Second Edition. 8s. net.

THE HODSOCK BALLISTIC TABLES FOR RIFLES. By F. W. Jones. Demy 8vo, 10s. 6d. net.

MECHANICAL DRAWING. With Special Reference to the Needs of Mining Students. By Joseph Husband, B.Eng., A.M.I.C.E., Professor of Civil Engineering at Sheffield University. With 40 plates. Quarto, 3s. 6d. net.

MACHINE SKETCHES AND DESIGNS. By Professor A. CRUICKSHANK, M.I.Mech.E., and R. F. McKAY, M.Sc., A.M.Inst.C.E. viii + 40 pages of illustrations, with short Explanatory Notes. SECOND EDITION. Quarto, 2s. 6d. net.

PETROL ENGINE CONSTRUCTION AND DRAWING. By W. E. DOMMETT, Wh. Ex., A.M.I.A.E. 26 plates, with descriptive letterpress and questions for technical students. Demy 4to, 3s. 6d. net.

EXAMPLES IN ELECTRICAL ENGINEERING. By J. F. GILL, M.Sc., B.Eng., A.M.I.Mech.E.; and F. J. TEAGO, M.Sc., M.I.E.E., The University, Liverpool. SECOND EDITION. Crown 8vo, 7s. 6d. net.

EXERCISES IN ELECTRICAL ENGINEERING. For the Use of "Second Year" Students in Universities and Technical Colleges. By T. MATHER, F.R.S., M.I.E.E.; and G. W. O. HOWE, D.Sc., M.I.E.E. THIRD EDITION. Crown 8vo, 2s. net.

GEOLOGY AND MINING

THE GEOLOGY OF THE BRITISH EMPIRE. By F. R. C. REED, Sc.D., F.G.S., formerly Assistant to the Professor of Geology in the University of Cambridge. viii + 480 pages, with 25 maps and sections. Demy 8vo, 30s. net.

COAL IN GREAT BRITAIN. By WALCOT GIBSON, D.Sc., F.G.S., F.R.S.E., Head of the Geological Survey of Scotland. viii + 312 pages, with 50 diagrams and 8 plates. Demy 8vo, 21s. net.

OIL FINDING: An Introduction to the Geological Study of Petroleum. By E. H. CUNNINGHAM CRAIG, B.A., F.G.S. SECOND EDITION. SECOND IMPRESSION. xii + 324 pages, 13 plates and 20 illustrations. Demy 8vo, cloth, 16s. net.

THE DRESSING OF MINERALS. By H. LOUIS, D.Sc., M.I.M.E., M.Inst.C.E. x + 544 pages, 416 illustrations. Super royal 8vo, cloth, 30s. net.

WINDING ENGINES AND WINDING APPLIANCES: Their Design and Economical Working. By G. MCCULLOCH, A.M.I.M.E., and T. C. FUTERS, M.Inst.M.E. viii + 452 pages, 175 illustrations. Demy 8vo, 21s. net.

A TEXTBOOK OF GEOLOGY. By P. LAKE, M.A., F.G.S., Reader in Regional and Physical Geography in the University of Cambridge; and R. H. RASTALL, Sc.D., F.G.S., Lecturer in Economic Geology in the University of Cambridge. xiv + 508 pages, fully illustrated. THIRD EDITION. Demy 8vo, 21s. net.

OUTLINES OF PALÆONTOLOGY. By H. H. SWINNERTON, D.Sc., F.G.S., Professor of Geology at University College, Nottingham. xii + 420 pages, with 368 diagrams. Demy 8vo, cloth, 30s. net.

THE GEOLOGY OF ORE DEPOSITS. By H. H. THOMAS, M.A., B.Sc., and D. A. MACALISTER, Assoc. R.S.M., of the Geological Survey of Great Britain. xii + 416 pages and 65 illustrations. Crown 8vo, 8s. 6d. net.

THE GEOLOGY OF BUILDING STONES. By J. ALLEN HOWE, B.Sc. viii + 455 pages, fully illustrated. Crown 8vo, 8s. 6d. net.

THE GEOLOGY OF SOILS AND SUBSTRATA. By the late H. B. WOODWARD, F.R.S. xvi + 366 pages, with illustrations. Crown 8vo, 8s. 6d. net.

GEOLOGICAL AND TOPOGRAPHICAL MAPS: Their Interpretation and Use. By A. R. DWERRYHOUSE, D.Sc., F.G.S. SECOND EDITION. viii + 133 pages, with 90 illustrations. Demy 8vo, 6s. net.

AN INTRODUCTION TO MINE SURVEYING. By T. BRYSON, A.R.T.C., M.I.Min.E., Lecturer at the Mining and Technical College, Wigan, and G. M. CHAMBERS, M.Inst.M.E. Fully illustrated. viii + 288 pages, 6s. net.

THEORY AND PRACTICE OF MINE VENTILATION. By T. BRYSON, M.I.Min.E. viii + 255 pages, with 81 illustrations. Crown 8vo. 8s. 6d. net.

CHEMISTRY AND METALLURGY

METALS AND METALLIC COMPOUNDS. By U. R. Evans, M.A., King's College, Cambridge. 4 vols., obtainable separately. Demy 8vo. Vol. I., 21s. net. Vol. II., 18s. net. Vol. III., 14s. net. Vol. IV., 18s. net.

THE CORROSION OF METALS. By U. R. Evans, M.A. Demy 8vo. xii + 212 pages. 14s. net.

ASSAYING IN THEORY AND PRACTICE. By E. A. Wraight, A.R.S.M., M.I.M.M. xii + 324 pages, 70 illustrations. Demy 8vo, 10s. 6d. net.

SERVICE CHEMISTRY. By the late Vivian B. Lewes, F.I.C., F.C.S.; and J. S. S. Brame, F.I.C., F.C.S., Professor of Chemistry, Royal Naval College, Greenwich. Fifth Edition. xvi + 576 pages. Illustrated. Demy 8vo, 21s.

FUEL. Solid, Liquid, and Gaseous. By J. S. S. Brame, F.I.C. Third Edition. xvi + 388 pages, 73 diagrams. Demy 8vo, 18s. net.

PETROL AND PETROLEUM SPIRITS. A Description of their Sources, Preparation, Examination, and Uses. By W. E. Gooday, A.R.S.M., D.I.C., A.M.Inst.P.T. With a Preface by Sir John Cadman, K.C.M.G. xii + 135 pages. Illustrated. Demy 8vo, 10s. 6d. net.

THE ABSORPTION OF NITROUS GASES. By H. W. Webb, M.Sc., F.I.C., Head of Chemistry Department, Cardiff Technical College. Illustrated. Demy 8vo, 25s. net.

THE CHEMISTRY AND TESTING OF CEMENT. By C. H. Desch, D.Sc., Ph.D., Professor of Metallurgy in the University of Sheffield.
[*New Edition in Preparation.*

THE RARE EARTHS: Their Occurrence, Chemistry and Technology. By S. I. Levy, M.A., F.I.C. xvi + 362 pages. Demy 8vo. 18s. net.

THE CHEMISTRY AND MANUFACTURE OF HYDROGEN. By P. Litherland Teed, A.R.S.M., A.I.M.M., Major R.A.F. Illustrated. Demy 8vo, cloth, 10s. 6d. net.

THE PRINCIPLES OF APPLIED ELECTRO-CHEMISTRY. By A. J. Allmand, D.Sc., Professor of Chemistry, King's College, London, and H. J. T. Ellingham, B.Sc. Second Edition. Medium 8vo. xii + 727 pages and 171 diagrams. 35s. net.

ANTIQUES: Their Restoration and Preservation. By A. Lucas, F.I.C. Crown 8vo. 6s. net.

FORENSIC CHEMISTRY. By A. Lucas, O.B.E., F.I.C. viii + 268 pages. Demy 8vo, 15s. net.

OUTLINES OF ORGANIC CHEMISTRY. By E. J. Holmyard, M.A., F.I.C. viii + 456 pages. Crown 8vo. 7s. 6d. net.

ORGANIC CHEMISTRY FOR ADVANCED STUDENTS. By Julius B. Cohen, Ph.D., B.Sc., F.R.S. Fourth Edition, in Three Parts. Each Part obtainable separately. 18s. net. Demy 8vo, cloth.

LECTURES ON THEORETICAL AND PHYSICAL CHEMISTRY. By the late Dr. J. H. van 't Hoff. Translated by R. A. Lehfeldt, D.Sc. Part I. Chemical Dynamics. 12s. net. Part II. Chemical Statics. 8s. 6d. net. Part III. Relations between Properties and Composition. 8s. 6d. net.

BIO-CHEMISTRY. A Study of the Origin, Reactions, and Equilibria of Living Matter. By the late Benjamin Moore, M.A., D.Sc., F.R.S., Whitley Professor of Bio-Chemistry in the University of Oxford. viii + 340 pages. Demy 8vo, 21s. net.

CHEMICAL DISINFECTION AND STERILIZATION. By S. Rideal, D.Sc., F.I.C., and E. K. Rideal, M.A., D.Sc., F.I.C. 321 pages. Demy 8vo, 21s. net.

SMOKE. A Study of Town Air. By Prof. J. B. Cohen, F.R.S., and Dr. A. G. Rushton. Second Edition, with 15 plates. Demy 8vo, 8s. 6d. net.

INDUSTRIAL POISONING. Translated from Dr. Rambousek's "Gewerbliche Vergiftungen" by Dr. T. M. Legge. Demy 8vo, 14s. net.

PHYSICAL CHEMISTRY: its Bearing on Biology and Medicine. By J. C. Philip, D.Sc., F.R.S., Professor of Physical Chemistry in the Imperial College of Science and Technology. Third Edition. Crown 8vo, 8s. 6d. net.

ELEMENTARY PHYSICAL CHEMISTRY. By W. H. Barrett, M.A., Harrow School. viii + 247 pages, with 61 diagrams. 6s.

THE CHEMISTRY OF COLLOIDS AND SOME TECHNICAL APPLICATIONS. By W. W. Taylor, M.A., D.Sc., Lecturer in Chemical Physiology in the University of Edinburgh. viii + 332 pages. Second Edition. Crown 8vo, 10s. 6d. net.

PRACTICAL CHEMICAL PHYSIOLOGY. By W. W. Taylor, M.A., D.Sc. Crown 8vo. Ordinary Edition, 4s. 6d. net; Interleaved Edition, 5s. net.

PRACTICAL PHOTOMICROGRAPHY. By J. E. Barnard, F.R.S., Director of Department of Applied Optics, National Institute for Medical Research, and F. V. Welch, F.R.M.S. Second Edition. Demy 8vo.

ANALYTICAL MICROSCOPY. By T. E. Wallis, B.Sc., Lecturer in Botany at the School of Pharmacy of the Pharmaceutical Society of Great Britain. viii + 150 pages. Illustrated. Crown 8vo, cloth, 6s. net.

AN INORGANIC CHEMISTRY. By H. G. Denham, M.A., D.Sc., Ph.D., Professor of Chemistry in Canterbury College, University of New Zealand. xii + 684 pages, with 144 diagrams. Crown 8vo, 12s. 6d. net.

INORGANIC CHEMISTRY. A Textbook for Colleges and Schools. By E. J. Holmyard, M.A., Head of the Science Department, Clifton College. viii + 564 pages, with 119 diagrams and 10 plates. Crown 8vo, 6s. 6d.

A HANDBOOK OF ORGANIC ANALYSIS: QUALITATIVE AND QUANTITATIVE. By H. T. Clarke, B.Sc., A.I.C. xvi + 264 pages. Third Edition. Crown 8vo, 6s. 6d. net.

THE CHEMISTRY OF BREADMAKING. By James Grant, M.Sc. Techn., F.I.C., F.C.S. Fourth Edition. viii + 232 pages. Illustrated. Crown 8vo, 6s. net.

CONFECTIONERS' RAW MATERIALS. By James Grant, M.Sc. Techn., F.I.C., F.C.S. viii + 174 pages. Illustrated. Crown 8vo, 8s. 6d. net.

AN INTRODUCTION TO BACTERIOLOGICAL AND ENZYME CHEMISTRY. By Gilbert J. Fowler, D.Sc., F.I.C. viii + 328 pages. Illustrated. Crown 8vo, 8s. 6d. net.

AN ELEMENTARY CHEMISTRY. By E. J. Holmyard, M.A. viii + 424 pages. Crown 8vo, 5s.

INORGANIC CHEMISTRY FOR SCHOOLS. By W. M. Hooton, M.A., M.Sc., Chief Chemistry Master at Repton School. 416 pages. Crown 8vo, 5s.

ELEMENTS OF INORGANIC CHEMISTRY. By the late W. A. Shenstone, F.R.S. Sixth Edition, revised and partly rewritten by R. G. Durrant, M.A. Crown 8vo, 6s. 6d.

OUTLINES OF INORGANIC CHEMISTRY. With Special Reference to its Historical Development. By E. B. Ludlam, D.Sc., F.C.S. xvi + 368 pages. Illustrated. Crown 8vo, 5s.

MINING PHYSICS AND CHEMISTRY. By J. W. Whitaker, B.Sc., Lecturer in the Mining Department, University College, Nottingham. xii + 268 pages. Crown 8vo, 9s. net.

QUALITATIVE ANALYSIS: IN THEORY AND PRACTICE. By P. W. Robertson, M.A., Ph.D., and D. H. Burleigh, M.Sc., D.I.C. 4s. 6d.

QUALITATIVE AND VOLUMETRIC ANALYSIS. By W. M. Hooton, M.A., M.Sc. Demy 8vo, 3s. 6d. net.

EXERCISES IN CHEMICAL CALCULATION. By H. F. Coward, D.Sc., and W. H. Perkins, M.Sc. viii + 152 pages. Crown 8vo, 3s. 6d. net.

FIRST AID IN THE LABORATORY AND WORKSHOP. By A. A. Eldridge, B.Sc., and H. V. A. Briscoe, D.Sc. Cloth, 1s. 3d. net.

BIOLOGY

FOUNDERS OF OCEANOGRAPHY AND THEIR WORK. By Sir William Herdman, C.B.E., D.Sc., F.R.S., Emeritus Professor in the University of Liverpool. xii + 340 pages, with 29 plates. Demy 8vo, cloth, 21s. net.

MANUAL OF ENTOMOLOGY. By the late H. Maxwell Lefroy, M.A., Professor of Entomology in the Imperial College of Science and Technology. xvi + 552 pages. Fully illustrated. Demy 8vo, cloth, 35s. net.

BRITISH HYMENOPTERA. By A. S. Buckhurst, D.I.C., L. N. Staniland, D.I.C., and G. B. Watson, D.I.C., Imperial College of Science and Technology. With many illustrations. Crown 4to, 9s. net.

THE MECHANISM OF LIFE. In Relation to Modern Physical Theory. By J. Johnstone, D.Sc., Professor of Oceanography in the University of Liverpool. xii + 248 pages, with 53 diagrams. Demy 8vo, 15s. net.

A STUDY OF THE OCEANS. By J. Johnstone, D.Sc. Illustrated. Demy 8vo, 10s. 6d. net.

ANIMAL LIFE IN DESERTS. By P. A. Buxton, M.A. xvi + 172 pages, with 14 plates. Demy 8vo, 10s. 6d. net.

GROWTH. By G. R. de Beer, B.A., B.Sc., Fellow of Merton College, Oxford. Demy 8vo. 7s. 6d. net.

AN INTRODUCTION TO THE STUDY OF THE PROTOZOA. With special reference to the Parasitic Forms. By the late E. A. Minchin, M.A., Ph.D., F.R.S. xii + 520 pages, 194 diagrams. Demy 8vo, 25s. net.

HUMAN EMBRYOLOGY AND MORPHOLOGY. By Sir Arthur Keith, F.R.S., M.D., F.R.C.S., Conservator of the Museum and Hunterian Professor, Royal College of Surgeons, England. Fourth Edition. Demy 8vo, 30s. net.

THE MIGRATIONS OF FISH. By Alexander Meek, M.Sc., F.L.S., F.Z.S., Professor of Zoology, Armstrong College, Newcastle-on-Tyne. With illustrations and maps. xx + 428 pages. Demy 8vo, 18s. net.

ARBOREAL MAN. By F. Wood Jones, M.B., D.Sc. With 81 illustrations. Demy 8vo, 8s. 6d. net.

THE DEVELOPMENT OF BRITISH FORESTRY. By A. C. Forbes, F.H.A.S. xii + 274 pages, 70 illustrations. Demy 8vo, 10s. 6d. net.

MANUAL OF HUMAN PHYSIOLOGY. By Leonard Hill, M.B., F.R.S. xii + 484 pages, with 177 illustrations. Crown 8vo, 6s.

ANIMAL BEHAVIOUR. By C. Lloyd Morgan, LL.D., F.R.S. Second Edition. viii + 344 pages, with 26 illustrations. Crown 8vo, 8s. 6d. net.

A HANDBOOK OF THE CONIFERÆ AND GINKGOACEÆ. By W. Dallimore and A. B. Jackson. With 32 plates and 120 diagrams. Medium 8vo, cloth, 42s. net.

A CLASS-BOOK OF BOTANY. By G. P. Mudge, A.R.C.Sc. (London), F.Z.S., and A. J. Maslen, F.L.S. Crown 8vo, 8s. 6d. net.

DATE DUE

	OCT 16 1970		AUG 29 1989
NOV 9 1970			
	RETURNED		
NOV 16 1970			
DEC 8 1970			
MAR 9 1971			
	RETURNED		
MAY 4 1975			
MAY 25 1976			

DEMCO 38-297

YOUNGSTOWN STATE UNIVERSITY
3 1217 00421 0400